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RAND FALLOUT SYMPOSIUM

Compiled By

S. M. Greenfield and R. R. Rapp

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1 April 1957

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PREFACE

A symposium on the subject of radioactive fallout resulting from nuclear-weapon detonations was held on March 5, 6, and 7, 1957, at The RAND Corporation, Santa Monica. It was sponsored by RAND and conducted under the chairmanship of Dr. Paul C. Tompkins, Scientific Director of the U.S. Naval Radiological Defense Laboratory. This paper presents the proceedings and significant conclusions of the conference, together with the research papers which were submitted for publication.

The purpose of the symposium was to examine the state-of-art of fallout research, and to define the major problems which must be solved if fallout phenomena are to be adequately understood. Five major topics comprised the agenda. These, with their individual chairmen, are as follows:

I.	Cloud Geometry	L. Machta (U.S. Weather Bureau)
II.	Particle Studies	J. Magee (Weapons Systems Evaluation Group)
III.	Meteorology	R. R. Rapp (The RAND Corporation)
IV.	Ground Distribution	G. Felt (Los Alamos Scientific Laboratories)
V.	Accuracy and Scaling . . .	S. M. Greenfield (The RAND Corporation)

The symposium program was designed to be as informal as possible. Formal presentations were limited, for the most part, to brief introductory talks for each of the discussion sessions. Following these keynote talks, open discussion was invited from the floor. Attendees, and their affiliations, are listed below.

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As the table of contents indicates, the plan of this paper parallels that of the symposium itself. A section, Opening Remarks, is followed by a section (I – V) for each of the discussion topics. Each of the numbered sections contains a brief account of proceedings, and a summary as prepared by the session chairman. Written papers which were submitted appear as appendices to this report.

CONCLUSIONS-IN-BRIEF

Although progress is being made in fallout research (e.g., dynamics-of-arrival measurements and particle studies), our understanding of the physical phenomena of fallout is frighteningly poor. Past weapons tests have relegated to a minor role the collection and understanding of fallout data. Unless proper emphasis is placed on fallout analysis in future tests, the fallout research program will continue to be severely handicapped.

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OPENING REMARKS

The symposium was opened by E. J. Barlow, Chief of RAND's Engineering Division, who welcomed the attendees and expressed hope that the conference would advance our knowledge of both the phenomena of fallout and its implications for military operations. He then relinquished the floor to Symposium Chairman P. C. Tompkins of USNRDL.

In his broad introduction to the symposium, Tompkins began by stressing the "working-group" nature of this meeting as contrasted with the more formal type in which a detailed agenda is prepared in advance. Then he posed the question: What are the kinds of things to look for as the outcome of a meeting of this type? He noted that the symposium might be oriented toward some specific purpose, such as the gathering of personnel-safety data for use in nuclear tests (How far away do you have to be? How soon can you enter the area? What kind of shelters will be needed?). Or, it might be oriented toward planning fallout countermeasures systems, which would require data on rate of formation, spread-versus-time, time-to-peak, etc. These and other specific "purposes" are all very important, Tompkins stated, but even more so is a broad state-of-the-art approach to the fallout problem. It is this last approach that should govern the present symposium.

To understand and adequately describe the fallout phenomenon, one should start with Time Zero, or the time of birth of the atomic cloud, and then follow through all the dynamics of the fallout process to termination. Thus, the entire spectrum of events should be considered.

Tompkins then proposed three ground rules for the symposium: (1) Be liberal in stating indications and trends that our discussions lead us to believe are reasonable; (2) Be conservative in drawing affirmative conclusions. 8

There has been too much of the business of going out on a limb to make sweeping generalizations about phenomenology, the nature of which we really do not understand; and (3) Aim for a clear statement of the important questions that must be answered during the course of the next few years. We might consider the symposium a singular success if out of it comes such a statement, together with suggestions on the most promising lines of attack for resolving the questions.

Tompkins then proposed the following questions as important enough to warrant immediate consideration: (1) Can we determine the material balance in the atmosphere affected by the fallout? (2) Can we predict fractionation satisfactorily? (3) Can we predict the complete history of the event? and (4) Is it desirable that the conference agree on a set of conventions for expressing data in fallout investigations?

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I. CLOUD GEOMETRY

A. PROCEEDINGS

Session Chairman L. Machta (USWB) commented on some of the work now being done on cloud geometry and then introduced W. Kellogg of RAND. Kellogg presented a prepared talk in which he attempted briefly to define some of the major questions confronting workers in this field. The essential content of his talk and of the discussion which followed appears in Section I(B).

After Kellogg's talk, Tompkins stated that perhaps in the past we have not been radical enough in the kinds of questions to which we have addressed ourselves. For example, we should consider the role of radio astronomy in obtaining information on atomic clouds. Perhaps such a technique would enable us to develop a means for picturing the maximum concentration of the origin of nuclear activity in nuclear bursts, as opposed to picturing activity occurring at later times.

By way of recapitulating the morning's discussion, Machta and Tompkins pointed up some of the things we need to know about atomic clouds in order to evaluate fallout intelligently, but about which we are still uncertain. For example, what is the actual shape of the cloud at different times? Is it spheroid, or pancake in shape? How does the shape change with time, if it does in any significant way? What is the spatial distribution of radioactivity in the cloud? Can we describe the radioactivity distribution as a function of yield, bomb type, height of burst, time of day, or meteorological conditions such as the troposphere height and the wind variation? Can we describe the activity of the cloud, and perhaps the fallout, as a function of ground-zero location, or of the type of ground cover, or the

ground environment as defined in other ways? And finally, how can we collect the data that will give us the information we need?

B. SESSION SUMMARY

Present State of Knowledge on Atomic Cloud Geometry

Kellogg, Machta, Schuerte

Part 1.

1.1 The parameters of a stabilized nuclear cloud, such as heights and widths, used in predicting fallout are still being derived, more or less, from the visible or optical cloud dimensions. These predicted visible cloud dimensions are based almost exclusively on interpolation or extrapolation of similar data from previous atomic detonations. While it is fairly certain that the cloud geometry is dependent on (a) the yield and type of burst, (b) the height of burst, and (c) meteorological conditions, usually the amount of rise and other cloud parameters are chosen from the yield alone. Particularly disturbing is the inability to show a significant influence of meteorological conditions on the cloud dimensions.

The two test series in recent years from which more cloud geometry might be expected were Teapot and Redwing. The entry of cloud geometry data to a plot of cloud dimensions vs yield shows about the same scatter around a best fit line as existed for previous nuclear clouds. It was hoped that the scatter* about the best fit line of cloud dimensions vs yield was due to errors of observation. The failure of the Teapot points, which were unusually reliable, to fit the curve better than previous points was therefore disappointing.

1.2 A major advance achieved during Redwing has been obtained by rocket and aircraft probing of megaton-yield clouds. This information is given in greater detail in Part 2 below. The essence of the findings,

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*For the amount of rise, the average departure from the best fit line is about 5 per cent of the total rise.

preliminary at present,* is that a horizontal probe through the lower part of the mushroom cloud shows two peaks in radioactivity. This is the picture to be expected if the radioactivity is mainly contained in the toroidal ring. Second, evidence suggests that the greater radioactivity is in the lower part of the mushroom.** The decrease with altitude through the mushroom appears to be faster than expected from a theory of uniform mass concentration resulting from mixing. Finally, radiation in the stem appears to be very significantly lower than in the mushroom.

The failure to simultaneously obtain good visible pictures of the Redwing clouds which were probed by rockets has prevented the comparison of the visible and radioactive clouds. The few reported aircraft penetrations of nuclear clouds have suggested that there is measurable radioactivity wherever the visible cloud is penetrated. However, the profile through the cloud shows relatively low values near the edge of the visible cloud. On the other hand, indirect evidence was also presented (by Dr. A. V. Shelton and others) to the effect that the radiological cloud was appreciably smaller than the visible cloud, as intuition would suggest. It seems fairly certain that the bulk of the radiological cloud, at least in the mushroom, is significantly smaller than the visible cloud.

Another promising means of obtaining information on cloud geometry has been demonstrated by Dr. D. Swingle. It consists of radar pictures of the developing atomic cloud. Techniques and obvious limitations are described in Part 3.

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*Further, as noted in Part 2 below the measurements do not distinguish between fallout and non-fallout particles.

**This is supported by information from fallout data from both Nevada and Redwing tests.

Another possible technique for obtaining the width of nuclear clouds is derived from the observed ground fallout pattern. If the locus of points of fallout from a certain height in the nuclear cloud can be found, which represents the edge of the fallout (radex) plot, then the width of the fallout pattern beyond this line describes the cloud radius at the given height (plus the effects of lateral diffusion). This kind of information has already been used to rule out the possibility of unusually large radii as suggested by certain visible cloud diameters, at least as far as fast-falling particles are concerned.

1.3 It is agreed that a coherent theory to predict, among other things, the cloud dimensions from the nature of the explosion and its environment would be highly desirable. It may be stated, however, that little or no success has been achieved beyond the early and very simple computations of Kellogg. Kellogg's information refers to the amount of rise of cloud and is incorporated in his picture of cloud rise vs yield.

There is a growing feeling, derived in part from more observations, that the toroidal ring plays an important role in the evolution of the nuclear cloud. It is suggested that a theoretical attack along these lines might hold some promise.

There has been little or no progress in recent years to improve upon the empirical formulae to predict could dimensions. These formulae have shown only slight value and efforts are now in progress to find either new controlling elements or better relationships.

1.4 The role which the device or the immediate surroundings plays in the cloud evolution appears to be uncertain. Evidence of unusual cloud development with "peculiar" devices was questioned because of the small

mass of the device. Further, there appears to be no significant difference in cloud rise between ground, tower and air bursts. Nevertheless, the failure of certain nuclear clouds to behave "normally" when meteorological conditions are "normal," suggests that as-yet-unknown factors pertaining to the weapon or its immediate surroundings may be important.

1.5 Certain promising avenues of research to improve the description and understanding of nuclear cloud geometry are suggested:

(1) Augmentation of the cloud probing by aircraft and rockets to include particulate sampling. Balloons and parachutes might be instituted as sampling platforms. Further, documentation of the visible as well as the radiological cloud should be part of such a program.

(2) The use of radar in conjunction with optical photography should be pursued.

(3) The possibility of scaling from smaller explosions and of obtaining suggestions from naturally rising air masses, such as in thunderstorms, should not be overlooked.

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Part 2.

2.1 In Project 2.66 of Operation Redwing (reported in ITR 1320), Col. Penson and his colleagues penetrated the clouds of several shots with manned aircraft, both through the base of the mushrooms and through the stem at times from H + 20 minutes to something greater than H + 1 hour. Measurements were made of the extent of the visible cloud and compared with measurements of the radiological cloud. The conclusions were:

(1) There was no significant difference observed between the visible and radiological cloud edges. However, the bulk of the radioactivity falls within a radius appreciably smaller than the radius of the visible cloud.

(2) The measured dose rates at the lower altitudes or in the stem (30,000 to 40,000 ft) were considerably lower than at higher altitudes in or near the mushroom (40,000 ft - 50,000 ft). On an average the difference was a factor of from five to ten.

(3) A typical plot of activity as a function of time on horizontal flights through the mushroom indicates a weak bimodal distribution.

2.2 As a result of the work done by R. D. Soule, Project 2.61, Operation Redwing, ITR 1315, 40 rockets carrying transducers telemetered gamma dose-rate as a function of position for four detonations. Salvos were fired at H + 7 minutes and H + 15 minutes. Certain limitations can be put on the data at this time because of a questionable time base which is being resolved.

The following conclusions are suggested:

(1) There is evidence of a bimodal distribution of activity in the mushroom along a horizontal line.

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(2) There is less positive evidence of a concentration of activity in the base of the mushroom.

(3) If photographic data are available on the dimensions of the optical cloud, it will be possible to compare the relation of optical to radiological clouds.

(4) One salvo of rockets was fired in a horizontal fan through the upper middle stem of a Redwing cloud. The results indicated that there is activity in the stem.

2.3 Measurements of activity profiles in the stems and mushrooms cannot be taken as a model parameter to define the activity that is contributing to the fallout pattern. We must, but are so far unable to, differentiate between total fission product activity and that portion of the activity which contributes to the fallout. Therefore, particle size distributions in the various parts of the cloud at early times should be measured.

Part 3.

3.1 During Redwing, Dr. Donald Swingle, of the SCEL, was able to obtain some radar pictures showing the atomic cloud in various stages of its development and decay. The following are the salient features of these observations (as reconstructed from a talk with Dr. Swingle in October, 1956):

3.1.1 A CPS-9 radar on Eniwetok observed the Apache cloud, which rose to a maximum altitude of about 84,000 ft, then sank back in the five or ten minutes following stabilization to about 70,000 ft. These were presented on a range-height scope. The picture showed the stem and mushroom of the cloud, but with some attenuation of the back side of the mushroom. There was a veil, or curtain, hanging down from the forward edge of the mushroom, and a similar veil, though much fainter, on the back side. A faint diffuse image of the cloud was still visible on the scope at about 3 hrs, but it had sunk to 25,000 ft and drifted away.

3.1.2 Similar pictures for the Huron shot, on the Eniwetok CPS-9. On this occasion the cloud again persisted for two to four hours, but was more compact.

3.1.3 On Tewa shot the Estes' radar observed the top at about 100,000 ft, sinking back rapidly to 80,000 ft. There was some question, however, about the calibration of this radar set.

3.1.4 The Tewa shot, though set off on Bikini, was observed by the CPS-9 on Eniwetok. It was observed to rise, and observers were able to see the faint persistent portion drifting toward Eniwetok for an hour or more.

3.1.5 Following the Tewa shot, later in the day, there appeared

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some curious vertical echoes on the r - h scope, which started at a high altitude and extended upward to 70,000 or 80,000 ft (far above the tropopause). They suggested in appearance the vertical precipitation cores observed in cumulus showers, but it would seem impossible to explain them in terms of precipitation at such a great altitude.

3.2 It was agreed in the meeting that these radar observations were of great potential value in studying the atomic cloud. However, it is premature to base any definite conclusions on them, since there is considerable uncertainty concerning what it is that accounts for the backscatter in the various parts. The Signal Corps is planning further and better documented radar cloud observations at Plumbob.

II. PARTICLE STUDIES

A. PROCEEDINGS

In his introduction Session Chairman J. Magee (WSEG) stated that WSEG's primary interest in fallout is its operational implications. But to understand these implications, he went on, it is essential first to study the basic physical and chemical phenomena of the process, the goal of which is a reasonable model for fallout calculations and prediction. Magee then introduced P. LaRiviere of USNRDL. (See Section II(B) and Appendix A for a summary of LaRiviere's remarks.)

After LaRiviere's talk, Magee expressed again his conviction that a model should be constructed showing the four stages of a surface burst and the activity that exists in each. The stages are (1) the burst itself and the development of the shock wave; (2) the beginning of toroidal circulation; (3) the mature toroidal circulation and the beginning of the mushroom; and (4) the high-altitude mushroom. A useful cloud model would fit particle information into this four-stage progression. At this point, P. Krey, U.S. Army Chemical Corps, offered some comments on particle size distribution (see Appendix B).

In the discussion following Krey's talk, Kellogg noted that some evidence exists which shows that in a low air burst, in which the fireball does not touch the ground, soil particles do not mix with the hot radioactive portions of the early cloud. Magee, pointing out that this may or may not be sensitive to the yield of the device, defined the primary question under discussion as that of how the particles are formed and how and when they become radioactive.

Krey postulated that as porous particles, such as those composed of coral, are heated, condensed radioactive liquid diffuses through their volume. Kellogg asked the question, if the column does not mix with the toroid in its hot early stages, how can particles in the column become radioactive? This topic was concluded with a statement from the floor that it is highly artificial to assume that particles exist only in the three types mentioned in LaRiviere's paper. Actually, we must recognize that there is a whole spectrum of particle shapes and sizes.

A. Anderson of USNRDL then presented some data on predicting fallout size distribution in a cloud. He demonstrated a mathematical model of size distribution, one assumption of which is that there are two forces acting on a particle. One force is that which carries the particle upward; the other is gravity, causing the particle to fall within the cloud. He noted that in the Jangle land-surface shot, which had a yield of 1.2 KT, all the radioactive particles were glassy, fused, and about 96% of them were irregular. His model is intended to apply to five seconds after burst, and he presented a number of plots showing size distribution with altitude and with time, of particles of specified sizes. His paper will soon be published by USNRDL. (See Appendix C for a preliminary draft of this paper.)

W. Hendricks of USNRDL was the next speaker. His paper, on the empirical determination of fallout cloud model parameters, is presented as Appendix D.

Hendricks' talk generated discussion on the possibility of using activity versus fall-rate to forecast fallout, bypassing particle-characteristics information such as size, shape, weight, etc.; that is, can we eliminate the problems of determining these various characteristics? Opinion appeared to be that this can be done as a purely temporary measure, but that to know

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anything, really, about fallout, we must know in detail what happens to the particles involved.

At this point Tompkins stated that his group, which is currently working on fallout countermeasures, requires specific knowledge of particle characteristics. Thus, particle size and shape would bear a definite relationship to such problems as that of decontaminating a ship by washing it down, or of similar problems of decontamination involving buildings, airfields, and the like.

S. Greenfield then interposed an objection to the implied assumption in the foregoing discussion that the major, or a major, objective of this session was to develop a cloud model useful for forecasting fallout. He stated that we are interested as well in a mechanism to explain fallout, and in the operational implications of the phenomenon. He emphasized that the purpose of the symposium, however, is not restricted to any one of these subordinate goals; rather, it is to discover what is known about the process, determine how to find out what is not known, and perhaps to agree upon some of the constants, or input data, that might be used in future calculations.

Magee then commented that it is important to know whether there is in fact a distribution of activity with particle size and fall rate, and if so, of what this distribution is a function. Additionally, it is important to know what fraction of the radioactive material comes out as local fallout and what fraction remains in the atmosphere and stratosphere to come down at later times.

From the floor came the question of fallout predictions for tests versus those for an actual D-day. It we know so little about fallout, given the

controlled conditions of peacetime testing, how much more difficult is the problem for a situation in which nothing is known, in advance, of the yield, the location of the burst(s), the meteorology, etc. Yet people such as those in Civil Defense appear to expect technical workers in fallout to produce "magic" numbers useful for prediction and planning by defense authorities.

It was agreed that one of the outputs of this symposium should be a statement stressing the invalidity for an actual wartime situation of any prediction made with the present state-of-art. Perhaps predictions should carry the label: Not to be Used for Operational Decisions.

Tompkins concluded this session by posing as a primary question: What fraction of fallout in a given shot will come down in significant quantities, and in what areas? In other words, how does one arrive at the material balance of an event? Also, how significant is the build-up of long-lived stratospheric or atmospheric radioactive materials? When and where will this material ultimately come down? Tompkins then raised other questions relating to the mechanism of fallout; e.g., does the particle size change by evaporation? Can one use the same parameters for water as for ground shots, given the present state of knowledge?

B. SESSION SUMMARY (J. Magee)

The material presented and discussed in this session can be summarized under two headings: (1) fallout particle studies, and (2) dynamics of particle transport.

A broad area of agreement was found in experimental results on fallout particles from shots of Operation Redwing. Results from NRDL and CWL were compared with respect to particle size, shape, chemical composition, and distribution of fission product activity, and were found to be in satisfactory agreement. A summary of available results is presented in Appendices A, B, and C.

Although details of particle formation and contamination are not understood, it is now generally agreed that most of the particles which carry activity have not been heated in excess of 800°C, as evidenced by their angular appearance (Appendix A). Since the mass of debris carried into the clouds of land-surface bursts is so large compared to that of the radioactive material, it would seem reasonable that the particles from the ground should form nuclei for collection of the fission products. Both the U.S. Army Chemical Warfare Lab. (Appendix B) and the U.S. Naval Radiological Defense Lab. presented evidence for a surface disposition of activity on fallout particles, which supports this point of view.

USNRDL presented data showing that the number of fissions per gram of fallout debris from Zuni was sensibly constant at several widely separated points in the fallout field. Tewa was not uniform, and considerable scatter was present in the Flathead and Navajo results, with no particular trend evident. The sample weights from the latter two events were very small, however, undoubtedly contributing to the uncertainty.

LaRiviere (NRDL) recommends the plotting of fallout activity in terms of fraction of device per unit area, as a more reliable measure of the total deposit than the hypothetical intensity at one hour after burst, thereby eliminating present uncertainties introduced by theoretical decay curves back to this time.

Studies of the dynamics of particle transport were presented by Anderson and Hendricks of NRDL. These studies were motivated by a dissatisfaction with the simple cloud models presently in use for the transport of fallout particles, and both were aimed at getting a better description of the cloud at early times. Anderson (Appendix C) considered the effect of fall of the particles during cloud rise. Hendricks (Appendix D) considered the problem of re-constructing a cloud (as it existed) at early times from the fallout field it created, with knowledge of the meteorological conditions.

III. METEOROLOGY

A. PROCEEDINGS

R. R. Rapp, Chairman of this session, introduced as first speaker E. Schuerte of USNRDL. Schuerte's topic was space-time wind variation. He opened his talk by stating that his efforts were directed toward defining the perimeter of a given fallout pattern and its "hot" line, or radiological axis. The contents of his paper appear in Appendix E.

At the conclusion of Schuerte's talk, Rapp expressed agreement on the necessity of taking into account time and space variations, basing his remarks on experience with Castle Bravo. He explained that the inclusion of time variations for this event resulted in a shift of the hot line between Bikini and Rongelap, which gave good agreement with the Bikini-measured results.

From the floor came the comment that it is one thing to take wind variations into account for tests, but that their value would be very doubtful for an actual D-day situation. In other words, the validity of a fallout forecast for operational purposes is poor. As an alternative, the suggestion was made that the use of present-day standard six-hour wind variations might be more practical. Rapp responded that, since our goal is a better understanding of the whole process of fallout and its prediction, space-time variation must certainly be considered.

The next speaker was J. Reed of Sandia. In the context of space-time corrections, he spoke about a forecasting-capability scale he had used. He considered particle trajectories and methods for reducing errors, and he proposed an objective method for deciding whether or not it was safe to go ahead with a test shot. For a report of his work, see Wind and Position

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Variability from Project Ramjet Data, J. Reed, Sandia Corporation Technical Memorandum.

The floor brought up the fact that constant-level balloons were very acceptable for measuring wind variation, since they remain at a particular altitude level in much the same way and for the same amount of time as a particle.

P. Allen from the U.S. Weather Bureau commented on the matter of wind variability at different altitudes and the use of balloons to gather data. His remarks are summarized in Appendix F.

A. Anderson (USNRDL) then spoke on some new upper wind measurement techniques he had been working on. His paper is summarized in Appendix G.

Rapp summarized the session by stating that meteorology presents a host of unsolved problems which we are currently trying to learn to live with. The situation appears gradually to be improving, and it is possible to foresee techniques in the future which will reduce the error and uncertainty that characterizes present work.

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B. SESSION SUMMARY (R. R. Rapp)

The meeting concurred on the necessity of taking space and time variations of the wind into account when a comparison of observed and computed fallout is undertaken. E. Schuerte of NRDL (Appendix E) presented the results of his analyses of the Redwing events to the group. His findings served to confirm the findings of the Weather Bureau Group on Nevada shots and the RAND studies of Castle Bravo.

Schuerte also presented the results of an attempt to incorporate vertical air motions in defining the fallout. His results were inconclusive. It was generally agreed that, theoretically, the vertical air motions should produce variations in the fallout pattern, but that our knowledge of such motions, at this time, is insufficient to demonstrate the effect.

J. Reed of Sandia Corporation presented the results of some work done by him and by the U.S. Weather Bureau on estimating the expected error of the axis of pattern. It was quite evident from results shown that, as in most meteorological problems, great effort must be put into the forecasts in order to gain just a few per cent of accuracy. It is felt that such error analyses are extremely important for test operations, because they provide the Test Director with a measure of the risk which must be taken when a device is to be fired.*

In connection with the error estimates which Reed explained, F. Van Straten pointed out the probable usefulness of constant level balloons.

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* Reed, Jack; Sandia Corporation, "On the Estimation of Fallout Safety Probabilities for the Nevada Test Site."
Weather Bureau report, "Distribution of Forecast Error."

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Such balloons provide trajectory measures at a given altitude. If a series of balloons could be coordinated with test firings, trajectories could be measured. This would go far in reducing the subjective analysis error which the Weather Bureau report shows to be a large fraction of the total error. Anderson pointed out two experimental methods of measuring wind which may be useful in this connection (Appendix G). P. Allen reported on some experimental forecasting procedures which show promise of improvement. The method is one which essentially predicts the mean wind in a thick layer (Appendix F).

Although it was obvious from the discussion that the meteorological problems in fallout forecasting are many, difficult, and in some instances incapable of complete solution, several optimistic trends were pointed out. First, serious efforts are being made to determine the distributions of expected errors, and these efforts are beginning to bear fruit. Second, a more precise definition of what needs to be forecast and the terms in which such a forecast should be presented is emerging. And last, forecast and measurement techniques which will improve the desired forecasts are being developed.

IV. GROUND DISTRIBUTION

A. PROCEEDINGS

Chairman Galen Felt (LASL) opened the session by asking the question, what precision can be attached to our observations of fallout deposition (dose rates, contours, etc.)? Further, how can these observations be used for calculating material or activity balances; i.e., what portion of the active material comes down, and where does it come down? It is important to know this both for the planning and conduct of tests and for estimating the long-range biological effects of nuclear explosions.

Felt then introduced T. Triffett (USNRDL), who spoke on the sources of error in the measurements we make, emphasizing, however, that we must depend upon such measurements since they are all we have. Triffett's paper is presented here as Appendix H.

At the conclusion of this talk, LaRiviere commented on the time-dependent parameters he calculated for Redwing (see Appendix J). He noted a rather peculiar relationship between the time of arrival and the time of peak activity, in which the time-to-peak appeared to equal twice the time of arrival. He could offer no explanation for this, and presented it merely to see if anyone else could. The response was negative, and Felt introduced L. Werner of USNRDL, after noting that errors in the measurement field seem to be running neck and neck with those in meteorology.

Werner's topic was the per cent of radioactive debris removed by fallout. To his own question, why is it necessary to determine the fraction of device contributing to fallout, he gave three answers: to check on fallout contours, to establish parameters, and to estimate the

contribution of fractionation to long-range fallout. His paper appears as Appendix K.

C. Miller (USNRDL), whose paper is summarised in Appendix L, stated that his primary interest was in evaluating countermeasures systems and reclamation procedures. He stressed that we need to know the dose-time curve for all situations, since it is an essential factor in estimating the duration of operational and final recovery phases after a nuclear attack.

Finally, K. Street (UCRL) presented some data on gas sampling at Redwing (actually a single shot) which tended to support the contention that 80% or more of the activity fell out locally. His comments and data are presented in Appendix N.

B. SESSION SUMMARY (Galen Felt)

1. Five papers were presented by members of the NRDL delegation. The full text of Triffett's paper on surface fallout measurements appears in Appendix H. Short resumes of the talks of LaRiviere, Werner, Miller and Baum are presented in Appendices J, K, L, and M.

2. A very great deal of discussion was stimulated by Werner's paper on the fraction of the device contained in local fallout (Appendix K). By Thursday afternoon, when the symposium could return to the subject, the following conclusions were reached:

a. All experimental evidence obtained by surface measurements (land and water) of fallout from PPG surface bursts and interpreted by NRDL leads to the conclusion that less than half of the activity is deposited in local fallout.

b. RAND interpretation (Tucker) of the same data leads to the conclusion that 80-90 per cent of the total device activity is deposited in local fallout. The RAND analysis is based on a different calibration, and the differences between RAND and NRDL can presumably be settled by further discussion.

c. Street (UCRL) presented data obtained by him in connection with his gas sampling project which led him to conclude that about 80-90 per cent of the device activity settles out locally from land-based shots. His estimate from a single sample (Redwing Huron) is that perhaps half of the device activity comes down locally from a water-based shot (Appendix N).

d. The experiments from which these results are drawn were not designed to answer the question of activity balance.

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e. Definitive conclusions on the question of the fraction of the device which settles out locally as a function of weapon characteristics and firing conditions cannot be drawn except in the most obvious cases.

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V. ACCURACY AND SCALING

A. PROCEEDINGS

Chairman for this session was S. Greenfield (RAND), who began by stating that growth comparisons are very useful for tests or for operational planning, and for telling us how well our models describe fallout. If we were able, ideally, to define all the parameters and the interactions among them, and then define the uncertainties, we would be well along the road to understanding the fallout process. In fact, however, we don't know all the parameters, the inaccuracies, and the interactions, so that what we have to rely on is, essentially, a pictorial design of the phenomenon. The question that should be asked, therefore, is: how well are we doing in describing the fallout pattern; i.e., how accurate are our predictions and evaluations?

V. Shelton (UCRL) then presented his paper (Appendix P) on the accuracy of fallout predictions his group had made and on the source of the model that was used. In the course of his talk Shelton pointed up the curious fact that, with an aluminum tower, fallout is increased two or three times over that obtained with a steel tower. B. Tucker (RAND) suggested that aluminum contains "more atoms per pound" than steel, which may account for the difference.

In the discussion following Shelton's paper it was brought out that the model he described yielded an accuracy that was less than a factor of 2. This generated some remarks on the relationship between accuracy and "precision," the substance of which was as follows: Accuracy of the overall measurement can't be any better than the accuracy of the best (most precise) instrument. When we talk about precision, we refer to the

error (or its absence) in the measurement as a whole, taken by all the instruments used. It seems reasonable that the accuracy of the overall measurement can't be better than the precision of the poorest instrument. In computing the results of a prediction, then, the forecast inaccuracies would be compounded by those of the post-shot measurements.

Greenfield spoke on the desirability of knowing the gross accuracy of the model used, exclusive of meteorological influences. In other words, given the present state-of-art in meteorology, it might be useful to test models under the assumption that perfect weather will obtain for the shot. He then discussed the Castle Bravo shots and the RAND models that were used. Rapp pointed out that RAND was actually trying to include more parameters in its model, complicating rather than simplifying it, in the hope of ultimately achieving a better fit for a greater number of tests.

Greenfield discussed two different ways of comparing an observed pattern with a calculated one: we can make a point-by-point comparison; or we can take a subjective view of the whole shape, then shift the pattern so that it agrees with the observed pattern, and then compare the points.

Anderson commented that, since a test shot has never been set up specifically for the purpose of obtaining fallout data, the symposium should recommend that this be done for a single Nevada shot. The results of such an arrangement could be used for evaluating our models. From the floor came the comment that AEC would not buy such a proposal.

Tompkins then declared that tests have always been set up for the purpose of testing weapons development, and that if we were to propose a

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test to measure the critical determinants of fallout phenomena, we would have to decide first just what kind of a test would be needed; i.e., we would have to agree on a sensible, concrete proposal before the AEC would buy it.

C. Ksanda (USNRDL) presented the last scheduled paper. He talked about scaling, which is essentially a field approach to the fallout problem, using variation in yield as an essential parameter and having no recourse to models or machines. Ksanda stated that not much was new in this field. The method in use is to take a Nevada test, for example, as a small-scale model of what would happen in a large-scale event. Ksanda cited seven assumptions used by his group, having to do with height of burst, yield, activity per unit volume, distribution of activity, winds, proportionality between activity and yield, etc. The end point of the calculations that are made is a dose rate which is proportional to yield. For further discussion of this subject, see Section V(B).

This session was concluded with a presentation by K. Nagler (U.S. Weather Bureau) of some recently compiled data on the total fraction of fallout from Nevada shots. These data are contained in Appendix Q.

B. SESSION SUMMARY (S. M. Greenfield)

Accuracy

The introductory paper for this session was given by V. Shelton of UCRL (Appendix P). In this paper he discussed fallout forecasting experiences at Nevada Tests. Fallout patterns generated in Nevada are somewhat unique in that the majority of the patterns appear as forecast, and any meteorological uncertainty is evidenced by an angular shift of the entire pattern. If no uncertainty exists in yield, height of burst, and meteorology, then the model presently used is apparently capable of predicting what will be observed to something better than a factor of ± 2. Such a confirmation of the model's ability is thought to be obtained when 50 per cent of the observations are matched by calculation to within this factor of 2. It should also be noted that the area of confirmation for this model lies within 20 - 100 miles of ground zero.

In the case where an uncertainty exists in the yield but the winds are well known, it is felt that the factor within which good confirmation is assumed to lie is increased from ± 2 to ± 3 - 4.

Due to the uncertainties that exist in the model and the observations, it is felt that for test operations the meteorology determines the accuracy. That is to say, if the winds are not varying in an unknown way, then the model is sufficiently accurate for test purposes, within the angular error provided by the known uncertainties in the wind movements and forecasts. If the winds are varying in an unknown or unsuspected manner, then the forecast pattern will be wrong under any circumstance.

What can be concluded from this session is the fact that what is described as "accuracy" is a function of what one is planning to use the fallout computation for. In the case of test operations, accuracy implies matching the majority of observations within the known error of measurement, and/or having the pattern lie within a sector determined by the wind plus the known uncertainties in the wind. In the case of studying the phenomenon itself, this is certainly not good enough. What is called for in this case, is a generally acceptable "standard" pattern against which a model can be tested utilizing something like a chi-squared test to establish a given level of significance. RAND is presently attempting to establish such a "standard" pattern.

Scaling

In the session on scaling, Charles Ksanda of NRDL aided by Mrs. Ruth Schnider, described NRDL's attempt to get analytical expressions for the various parameters, such as (1) weapon (fission) yield, (2) position of burst relative to the surface, (3) surface media (earth, water, etc.), (4) meteorological conditions, etc. (Ref. TM-23-200). It appeared that all scaling methods for fallout patterns so far devised work quite well. The reason for this apparent agreement in scaling, however, lies in the fact that there is an estimated uncertainty in the area within a given measured contour of a factor of 10*. This uncertainty is produced by such factors as measurement errors, subjectivity in drawing contours

*"Comparison of Methods Used in Scaling Residual Contamination Patterns Resulting from Surface Detonations of Nuclear Weapons" by Roger E. Boyd, Capt. USAF, Don Baker, 2nd Lt. USAF. 2 April 1956 AFSWC-TN-56-1, Air Force Special Weapon Center, Kirtland AFB.

from a relatively few points, etc. It is apparent that with such a large uncertainty it is possible to fit any scaling law to the existing data. Although no discussion followed these talks, Ken Nagler of the U.S. Weather Bureau presented some recently compiled data which summarized the estimates that have been made in the past of the total fraction of the activity that fell out of various shots in Nevada (Appendix Q). Aware of the uncertainties that exist in such estimates, The Weather Bureau has made an attempt to provide a minimum, a maximum, and a most probable fraction down for these same shots.

CONCLUSIONS

The following comments represent the major points expressed by Symposium Chairman P. C. Tompkins (USNRDL) in his summation of the results of the symposium and the current state of knowledge of fallout phenomenology:

o The symposium produced more new ideas than quantitative answers, although we might have been able to arrive at some numbers if advance research reports were available along with sufficient time to analyze them.

o Measuring the total fraction of the activity that actually falls out locally continues to be troublesome. We are still integrating ground observations of intensity in an attempt to make this measurement. We all realize that these intensity observations are just too uncertain to give any reasonable accuracy.

o Measuring the dynamics of the arrival, i.e., the time of start and stop of fallout, the rate of building of intensity, the size distribution, etc., which have gained more interest lately, is perhaps more fruitful than measuring the fraction down, since it gives a better insight into the phenomena of fallout.

o Particle studies, of the kind done by LaRiviere and others of NRDL, are also very useful, and these observations must be fitted into any prediction model.

o The scaling of parameters is seen to be of rather questionable accuracy—viz. Ksanda's (NRDL) review of the question. A prediction method should take into account the lack of accuracy of the detailed models used. Perhaps we should go to a much simpler method of presenting such predictions.

o The basic mechanism of the early fireball phenomena must be understood better. If such an understanding can be achieved, then we can visualize

a model that starts with height of burst, type of device, environment, etc., and achieves particle size-activity and activity-space distributions that are not subject to question. We would then be able to reconcile the difference between the various present models—or make a more rational one.

o What is still missing in this field is a clear-cut, unquestionable conversion factor for converting KT of fission energy per square mile to megacuries per square mile to roentgens per hour. This factor is absolutely necessary in interpreting the fallout data, and unifying the experimental technique.

o There are some hints in the experimental area which indicate that small fractions remain aloft (Street, UCRL); it is too bad that these cannot be reconciled with the analysis of the ground fallout (NRDL).

o The question of mushroom-vs-stem requires further analysis, and this can be done both by studying the dynamics of the rising cloud and by a better analysis of the observed fallout in terms of where it originated—with the time of arrival taken into account.

o There seems to be no basis for real agreement on the fraction down for a water shot or from a ground shot. We cannot even say that we can agree on whether it is > or < 50%. In short, our understanding of the physical phenomena of fallout is "frighteningly poor." We must make this fact known; it is our obligation to say that we just don't know enough at this time.

The lack of emphasis on the fallout program in past tests has resulted in a non-coherent program, in which the collection and understanding of fallout data has been relegated to a secondary or minor role. Our position will not be improved unless we insist on giving our true opinions about the effects of such a program on the state of fallout research.

APPENDIX A

Distribution of Particle Classes

P. La Riviere

	YFNB-13 TE	YFNB-29 TE	HOW-F TE	YAG-39 TE	YAG-40 ZU	YAG-40 TE	LST 611 TE	Overall Average (%)
Angular	73.7	65.9	85.6	59.5	63	54.4	72.7	63.0
Flaky	7.9	18.8	14.4	27.3	13	34.7	11.6	21.3
Spherical	18.4	15.3	0	13.2	24	10.8	15.7	15.7
No. of Particles	152	170	14	304	309	360	172	1481

ANGULAR: 1. $CaCO_3$, unaltered ($< 800^\circ C$)

2. Partial to complete decarbonation, formation of CaO. Porous; hydrated to $Ca(OH)_2$, with outer shell of $CaCO_3$. (800–$2570^\circ C$)

FLAKY: Possible result of rapid hydration $CaO^{(dV = \%100)}Ca(OH)_2$ ($\gtrsim 2570^\circ C$)?

SPHERICAL: CaO, dense structure, slow hydration. Some arrive in oxide form. ($\gtrsim 2570^\circ C$)

$800^\circ C$ – $900^\circ C$ $CaCO_3$ decomposes to CaO

$2570^\circ C$ CaO melts

$2850^\circ C$ CaO boils

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APPENDIX B

OPERATION REDWING RESULTS

Philip W. Krey

Chemical Warfare Laboratories

1. LAND SURFACE SHOTS

1.1 Fallout Particle Studies

The fallout from the three land surface bursts at Operation Redwing, Shots Lacross, Zuni and Tewa, was investigated in some detail. In general the particle size distribution of the total fallout occuring within the shot atoll area (at distances up to approximately 15 miles from Ground Zero) was similar to the particle size distribution of the coral native to the surfaces of the islands. Unfortunately, the exact size distribution of the native coral is not available at this time, but reasonable estimates of this distribution indicate that over 75 per cent of the total weight of the coral is contained in the 210 to 840 micronfraction. Table 1 summarizes the data obtained from all three land surface shots. The UAG 40 sample collected at approximately 50 miles from Ground Zero reflects a displacement of the size distribution toward the smaller particle size ranges. This behavior is reasonable because the greater terminal velocities of the larger particles should deplete their contribution to the total size distribution as the distance from Ground Zero increases.

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Total β activity/gram of fallout substantiates a non-uniformity of specific activity with fallout collected at different locations from a specific event and between different events.

The reported distributions were obtained by sieving the fallout sample and measuring each sieved fraction. The particle size ranges listed in Table 1 represent the ranges in the pore openings between subsequent sieves. Experience has indicated that for irregular type particles such as fallout, the size distribution of the particles on any sieve is usually displaced toward the upper limits of the range. Complete size distributions within each sieved particle size range are being measured.

The activity distributions of the fallout presented in Table 1 illustrate that about 60 per cent of the total activity in the fallout (occurring within the shot atoll from all land surface shots) is associated with particles greater than 200 microns; over 80 per cent of the total activity is associated with particles greater than 100 microns. In general, the activity distribution of the fallout with particle size parallels its

size distribution except for the 840 μ fraction. The 50-mile sample collected on the YAG-40 at Zuni Shot reflects an activity shift toward the smaller particles similar to its particle size distribution shift.

Two fundamental types of particles were observed by both USNRDL and CWL in the fallout from all three land surface bursts, namely angular and spherical particles. USNRDL reported a third type described as a fragile, flaky particle. Since the CWL's experimental procedure required sieving the fallout, the flaky particles could have been broken up and therby escaped detection of the CWL's samples.

1.1.1. Angular Particles

The angular particles which resemble natural coral are composed of $CaCO_3$ that has been heated and partially converted to CaO. In the presence of moisture and CO_2 in the air, the CaO can reconvert to $CaCO_3$. These particles presumably have been contaminated on their surfaces by radioactive debris from the atomic cloud. The radioactivity has diffused into the particles producing a volume distribution for small particles and a quasi-surface distribution for larger particles.

1.1.2 Sphericle Particles

1.1.2.1 Composition and Formation

The spherical particles were composed of CaO which had been converted in whole or in part to $Ca(OH)_2$. Some reconversion to $CaCO_3$ had occured on the surfaces of the spheres. These particles were probably formed by rapid heating of natural coral to temperature beyond the melting point of CaO in the vicinity of the fireball. The particles were not vaporized but assumed a spherical geometry in the molten state. The molten spheres scavenged activity from the fireball onto their surfaces and

generally distributed this activity throughout their volumes while in the fused state.

1.1.2.2. Frequency

There was some disagreement on the frequencies of the spheres in the Tewa Shot fallout as determined by USNRDL and the CWL. It was concluded that this discrepancy probably arose from the experimental procedures employed. The Navy counted each type of particle in an undisturbed sample and calculated the frequencies. The Chemical Corps physically separated the spherical particles from all other particles in the Tewa fallout to characterize the spheres in detail as compared to the others. A specific effort was made to minimize the contamination of the separated spheres by other types of particles. Consequently, if any doubt arose as to whether a particular particle was or was not a sphere, it was considered a non-sphere. Under these conditions, the lower frequencies of the spherical particles in the Tewa fallout determined by CWL can be qualitatively resolved with the higher values reported by NRDL.

This possible CWL bias is a constant factor in all the Tewa samples, so that the data can still be used to illustrate another characteristic of the spherical particles. The percentage of the total number of spheres in the Tewa fallout increased from 1.2 to 2.5 to 2.78 to 3.06 per cent in the size ranges of 149-210μ, 210-420μ, 420-840μ, and > 840μ respectively. The same general trend of increasing frequency of spherical particles with increasing particle size was observed at Zuni Shot. In the shot atoll Zuni fallout the frequency of the spherical particles increased from below 2 per cent by number in the 44-74 micron region to about 6 per cent in the 420-840 micron range. In the Zuni fallout collected at the YAG-40 station,

which was about 50 miles from Ground Zero, the frequency of the spheres increases to approximately 15 per cent in the 149-210 micron range. Consequently, the data illustrates a variation in the frequency of the spherical particles with both particle size and distance from Ground Zero. It is felt that a more detailed investigation as to whether there is an additional variation with shot conditions should also be made.

1.1.2.3. Relative Radioactivity of Spherical Particles

On the basis of the CWL measurements, the spherical particles were approximately 25 times as radioactive as the other types of particles combined in the Zuni fallout. If the Chemical Corps' frequencies are used, the spherical particles contributed about 60 per cent of the total activity of the solid fallout in the shot atoll and 80 per cent of the total activity of the solid fallout at the 50 mile station. At the Tewa Shot, the spherical particles were only 10 times as radioactive as the other types of fallout particles. On the basis of the frequencies determined by CWL, the spherical particles contributed about 25 per cent of the total activity of the solid fallout in the shot atoll area.

1.1.2.4 Relative Radiochemical Composition of Spherical Particles

The R values in Table 2 illustrate the degree of fractionation between the spherical particles and all other types of particles combined. The Mo^{99} and N_p^{239} analyses were performed under very poor conditions at the PPG when the background radiation following the Tewa Shot was so high. Perhaps these conditions were responsible for some of the poor precision obtained especially in the Mo^{99} analysis. Four aliquots were removed for each analysis; in general, three aliquots agreed quite well, but the fourth aliquot often exhibited wide variations from the first three. 48

No justifications were obvious for dropping the fourth aliquot, so they were averaged along with the rest. Omission of any aliquot would not change the average values very significantly, but it would greatly improve the apparent precision.

The relatively low concentrations of nuclides with rare gaseous precursors (i.e., Sr^{89} and Ba^{140}) in the spherical particles offers support to the concept of early contamination of the fireball. It is interesting to note that I^{131} behaves similarly to Sr^{89} and Ba^{140}.

1.2 Time Sequence of Events

In the light of these concepts of particle origin, the following sequence of events is postulated following a land surface shot. A column of water and coral is injected into the rising fireball by the rapidly rising column. This early column material is fused to form the spherical fallout particles which scavenge radioactivity from the highly concentrated fission products and debris at early times. As the fireball rises, expands, and incorporates more column material, the temperature decreases such that the coral particles are no longer fused. This later column material becomes the angular fallout particles which are initially surface contaminated by later debris from the resultant mushroom cloud.

2. WATER SURFACE SHOTS

The significant fallout from Flathead Shot consisted of droplets of less than a millimeter in diameter and composed of a shiny of salt water, salt crystals, $CaCO_3$ particles, and some ferric type particles. In the shot atoll following the Flathead event, this material arrived at sampling stations at an angle of approximately 30 degrees from the horizontal.

Similar fallout was observed following the Navajo Shot, although the angle of arrival was larger and the presence of iron was much lower. These results are in satisfactory agreement with USNRDL.

3. FURTHER INVESTIGATIONS SUGGESTED

Investigations should be conducted to answer the following questions:

1. Does the frequency of the different types of particles and their specific activities (activity per gram) vary with yield, type of burst, and underlying soil? It if does, how will it vary, and how will it effect the fallout prediction and counter-measures techniques?

2. Is there any variation, as the data suggests, in the relative frequencies of particle types as a function of altitude in the mushroom cloud?

3. Is the debris initially deposited on the surface of the angular particles liquid, gas, or particulate?

4. What are the densities of the various types of particles since their fall velocities are dependent upon size, shape, and density?

5. What are the times of arrival, rate of arrival, times of peak activity, and times of cessation for each type of particle?

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Table 1 — SIZE AND ACTIVITY DISTRIBUTION AS A FUNCTION OF PARTICLE SIZE FOR SURFACE LAND SHOTS AT OPERATION REDWING

Particle Size	Bravo Island Collector		Charlie Island Collector		Yoke Island Collector		YAG-40 Collector	
	% of Total Weight	% of Total Activity	% of Total Weight	% of Total Activity	% of Total Weight	% of Total Activity	% of Total Weight	% of Total Activity
< 44μ	1.8	—	—	—	0.7	1.8	3.5	7.3
44–74μ	4.6	6.5	—	15.5	4.4	9.9	10.2	12.5
74–105μ	2.3	3.2	—	8.1	2.8	6.0	13.9	15.5
105–149μ	2.0	2.5	—	8.5	2.5	5.6	17.2	13.6
149–210μ	2.4	2.8	—	9.3	2.8	7.5	32.3	36.1
210–420μ	9.0	12.0	—	24.9	6.8	12.3	21.0	15.0
420–840μ	38.0	54.0	—	23.8	27.2	42	1.5	—
> 840μ	40.0	19.0	—	9.8	52.9	15	0.3	—

Particle Size	Lacross Shot Gene Island Sample		Tewa Shot Bravo Island Collector	
	% of Total Weight	% of Total Activity	% of Total Weight	% of Total Activity
< 44μ	0.5	0.8	0.4	—
44–74μ	0.9	1.1	1.0	1.2
74–105μ	0.8	1.2	0.8	0.9
105–149μ	1.3	2.1	1.0	1.1
149–210μ	4.8	6.3	2.5	2.2
210–420μ	89.1	86.9	43.7	65.5
420–840μ	2.7	1.7	45.7	26.8
> 840μ	—	—	4.8	2.1

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Table 2 – RADIOCHEMICAL FRACTIONATION IN TEWA FALLOUT BETWEEN SPHERICAL AND ANGULAR PARTICLES

Sample	R Values				
Bravo Island Fallout Angular Particles	$\frac{Sr^{89}}{Mo^{99}} \pm \sigma^{*}$	$\frac{I^{131}}{Mo^{99}} \pm \sigma^{*}$	$\frac{Ba^{140}}{Mo^{99}} \pm \sigma^{*}$	$\frac{Ce^{144}}{Mo^{99}} \pm \sigma^{*}$	$\frac{\text{Capture}}{\text{Fission}} \pm \sigma^{*}$
149–210μ	0.137 ± 12 %	0.206 ± 16%	0.406 ± 7.9%	0.679 ± 8.1%	1.01 ± 7.5%
210–420μ	0.0995 ± 23 %	0.323 ± 25%	0.308 ± 23 %	0.595 ± 22 %	0.980 ± 37 %
420–840μ	0.138 ± 11 %	0.446 ± 19%	0.526 ± 7.0%	0.610 ± 6.3%	0.710 ± 4.2%
> 840μ	0.0614 ± 6.0%	0.167 ± 15%	0.252 ± 6.2%	0.525 ± 6.2%	0.856 ± 4.9%
Spherical Particles					
149–210μ	0.0474 ± 25 %	0.0648 ± 20%	0.131 ± 17 %	0.593 ± 17 %	1.47 ± 17 %
210–420μ	0.0179 ± 7.1%	0.0275 ± 12%	0.0704 ± 4.9%	0.784 ± 12 %	2.43 ± 31 %
420–840μ	0.00640 ± 18 %	0.0112 ± 11%	0.0248 ± 5.2%	0.444 ± 5.1%	0.940 ± 2.1%
> 840μ	0.00369 ± 31 %	0.00885 ± 28%	0.0140 ± 19 %	0.316 ± 18 %	0.732 ± 17 %

*The symbol, σ, represents the percent standard deviation of each reported value which is a measure of the precision of the analyses.

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APPENDIX C

A Theory for Close-In Fallout*

A. D. Anderson

Naval Radiological Defense Laboratory

A. Introduction

A theory that takes into account the fallout phenomena from the time of detonation to the time the mushroom cloud stops rising has been lacking. An attempt is made in this article to derive such a theory in order to find the altitude distribution of radioactive particles affecting close-in fallout, that is, fallout which is deposited on the ground within a few hundred miles of ground zero, and which is down within about 20 hours after detonation. The deposition of radioactivity in the immediate vicinity of a nuclear burst is dependent largely on the size distribution of active fallout in the mushroom cloud. Heretofore, there has been a lack of knowledge concerning these size distributions, mainly because of the complexity of the phenomena creating them. In this work, the theory developed is illustrated by a land-surface burst.

B. Assumptions Used in Theory

The theory developed is based upon the two following major assumptions, resulting from an analysis of available information concerning nuclear detonations:

1. The trajectories in the atmosphere of the radioactive fallout particles result mainly from the effects due to the rise of the mushroom cloud, gravity, and horizontal winds only.

*The work reported in this article is covered in more detail in an NRDL report of the same title, now in draft form.

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2. Most of the radioactive fallout is created within relatively short times after detonation (within one minute for yields up to 15 MT); consequently, the fallout process starts while the cloud is rising in the lower atmosphere.

Regarding assumption (1), the following description of a land-surface burst is given to aid in understanding it and the theory used.

After detonation, the fireball forms and starts to move upward rapidly within several seconds. Immediately afterward air, carrying surface material, rushes into the bottom of the rapidly-expanding fireball, resulting in the creation of a mushroom-shaped cloud with dust-laden stem. After the cloud has cooled to below about 2800°C none of the particles being taken into the cloud will be vaporized; they will be mixed thoroughly throughout the cloud volume by the intense turbulence, together with the radioactive fission products. The turbulence gradually subsides as the cloud expands and cools. The resulting radioactive particles will start to fall out as the cloud ascends, resulting in an altitude distribution of particle sizes, which becomes more marked the higher the cloud rises from the ground. After about two minutes the dust stem falls behind, and no more ground material enters the mushroom. The cloud stops rising by 5-7 minutes after detonation when its temperature becomes approximately equal to the ambient temperature.

When the cloud is being formed, the initial impulse of air into its bottom induces a toroidal circulation which persists usually until after the cloud has stopped rising. There are several hypotheses concerning the effect of this circulation on the particle size distribution; however, there is little evidence to support any of them. In the absence of evidence proving a significant effect, the net effect of the circulation on the

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gravitational settling of the gross fallout is taken to be negligible. The mean displacement of the center of gravity of the particles due to the circulation is assumed to be zero. The same remarks apply to turbulence; it does not, on the average, increase or decrease the time of fall, but it does result in an increase in particle dispersion. Admittedly, this theory is idealized; however, it is believed to be the most complete one that can be developed based upon present knowledge. The theory is sufficiently flexible so that if a significant effect can be demonstrated for the toroidal circulation or turbulence, then it can be taken into account.

Thus, on the average, the rate with respect to the ground with which a particle falls out of the cloud is equal to the difference between the velocity with which it is carried up by the rising cloud and the velocity with which it falls, due to gravity. At any time after burst the velocity of a particle with respect to the ground is

$$\dot{z} = U - V , \qquad (1)$$

where U is the particle's upward velocity due to the rise of the cloud, derived from measurements of the rate of rise of the top and base of the cloud, and V is its downward velocity due to gravity. Here $\dot{z}$ is taken to be positive when the particle is moving upward, that is, $U - V > 0$, and negative when the particle moves toward the ground, $U - V < 0$.

For many of the heavier particles, $V > U$ for short times after burst, and these particles will fall out of the cloud before it has stopped rising. Heretofore no attempt was made to take into account this important effect.

The particle's altitude above the ground, z, can be found at any time t by integrating (1), thus,

$$z = \int_0^t (U - V)\, dt + C , \qquad (2)$$

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where C is the integration constant. If z is expressed in feet above mean sea level and t in seconds and the velocities in feet per second, then C is equal to the height of ground zero above mean sea level in feet.

Regarding assumption (2), it will be discussed by considering first a low yield land-surface burst, illustrated by JANGLE-Surface, 1.2 KT. The radioactive fallout material consisted almost solely of glassy particles containing radioactive fission products within them(1). The elemental composition of these active particles was identical to that of the parent soil with the exception of carbon and boron, whose compounds are easily volatilized compared to compounds of the other elements present. The average density of the active particles was almost the same as that of the parent soil.(2) Evidently, the temperature experienced by the siliceous material was above 1700°C for the bulk of the radioactive fallout particles.(3) Consequently, the mixing between the molten earth particles and the radioactive fission products apparently occurred when the internal temperature of the fireball was above the melting point of the silicates, above 1700°C. Since it appears that a very large fraction of the particles in the fallout have not been vaporized, the gross size distribution of the fallout (both radioactive and inert) in the cloud should be the same as the original environmental material. Since the temperature of the fireball drops below 1700°C at about three seconds after burst for a 20 KT weapon,(4) for JANGLE-Surface, a 1.2 KT weapon, it has been concluded that most of the radioactive fallout was created and thoroughly mixed throughout the cloud by five seconds after detonation.

In the case of an air burst, there have been many cases in which surface material was carried up into the rising mushroom. In such cases

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there has been a negligible amount of radioactive fallout on the ground. Though tons of sand and dust were raised by the explosion, they did not become contaminated by the fission products.(5) This may be explained by the fact that it takes longer for the surface material to be carried up into the cloud resulting from an air burst than for a surface burst. By the time the material reaches the cloud it has already cooled below 1700°C; consequently, little radioactive fallout is created.

The time after burst within which most of the fallout was created can be found on the same basis, for other tests, by analyzing the characteristics of the fallout, both active and inert. For example, for the Pacific tests examination of the fallout, derived mostly from coral, indicated that most of the active fallout was created above 830°C,(3) within one minute after burst. This applies to weapons with yields up to about 15 MT. This suggests that the temperature below which fallout is created is not very sensitive to yield. Hence, it is concluded that the time from burst within which most of the active fallout is created is not very sensitive to yield, and that most of the active fallout is created within relatively short times after burst (within one minute at the latest) for up to 15 MT.

C. Illustration of Theory

This new theory of fallout will be illustrated by deriving particle size distributions with altitude at selected times after burst. The method used is as follows: (1) Time-altitude curves are derived, with the air of a nomograph of the cloud's rate of rise, for particles of selected sizes originating at the top (T-curve), middle (M-curve), and base (B-curve) of the mushroom cloud. The curves are started after fallout has been created, and terminated when they reach the ground. (2) These curves are used to

find the size distribution of fallout within selected altitude ranges at a later time by locating on them the top, middle, and base altitude points of each size at this time. (3) Using these points, curves are drawn for each particle size on a graph of "Cumulative per cent below stated altitude vs. Altitude." (4) The percentages of the total of each size within selected altitude ranges are determined from the graph, and these percentages are weighted according to the proportions of sizes found by weight in the preshot soil. (5) Finally, percentage frequency size distributions are derived from these percentages for the selected altitude ranges at the chosen time.

The method will be illustrated with data from the 1.2 KT JANGLE-Surface test conducted in Nevada on Nov. 19, 1951.

1. Derivation of Time-Altitude Curves

The integral in equation (2) can be approximated by a finite difference equation. Thus, if the time interval from 0 to t is divided up into smaller finite intervals, Δt_1, Δt_2, ... Δt_n, then

$$z = \sum_{i=1}^{n} (\bar{U}_i - \bar{V}_i)\Delta t_i + C = (\bar{U}_1 - \bar{V}_1)\Delta t_1 + (\bar{U}_2 - \bar{V}_2)\Delta t_2 + \cdots + (\bar{U}_n - \bar{V}_n)\Delta t_n + C \, . \qquad (3)$$

The barred velocities are average velocities for the time intervals indicated by the subscripts.

The average values of rates of rise, $\bar{U}_i$, in equation (3) were found from a nomograph derived from the time-altitude curves of the top, middle, and base of the JANGLE-Surface cloud. The nomograph contained fifteen curves, each of which gave the average rate of rise for all parts of the cloud and altitudes below the cloud for a selected time interval. The

time intervals for the curves comprised in total the period from 5 seconds after detonation to 300 seconds after detonation, the time at which the cloud stopped rising. The first time interval was equal to 5 seconds. The time intervals were chosen smaller at the start to allow for the greater changes taking place initially in the rates of rise. Since it was concluded that most of the radioactive fallout was created and thoroughly mixed throughout the cloud by five seconds after detonation, the gravitational settling, and hence the time-altitude curves, for the fallout was started at this time.

Individual time-altitude curves were made for irregular particles having diameters of 1, 50, 150, ..., and 1950 microns; three curves were made for each size, starting at the top, middle, and base of the cloud at 5 seconds after detonation and ending at 4000 feet msl (at about ground level). The 0-2000 micron size range was used because preshot soil size distribution data were available for this range. The method can be extended to larger sizes if desired. By using the method developed in this article, it was found that all particles greater than 2000 microns in diameter, comprising about 28 per cent by weight of the soil particles, fell out and reached the ground within four minutes after detonation, within one mile of ground zero. Ninety-three per cent of the particles from 0-2000 microns were less than 1000 microns in diameter, and 81 per cent less than 500 microns.

The $\bar{V}_1$ terms in equation (3) represent the average downward velocities of the particles during the time intervals indicated by the subscripts. For the sizes considered the velocities can be taken to be terminal velocities; that is, it is assumed that the drag forces acting on the particles are always equal and oppositely directed to the gravitational

forces. For instance, the largest particle considered, a 2000 micron particle, would reach its terminal velocity within 0.2 seconds after starting from rest. The aerodynamic equations were used to find the terminal velocities. They were applied for irregular-shaped particles since more than 96 per cent of the active fallout for JANGLE-Surface consisted of irregular-shaped glassy particles.(1) The density of the active particles, measured in the 150-500 micron range, averaged 2.66 gms per cm^3;(2) this value is almost the same as the value used, namely, 2.60 gms per cm^3, measured for the test site soil density. The air density and viscosity values were derived from the rawinsonde data taken at shot time at 14.25 miles from ground zero. The temperature data used to find the density and viscosity are for the atmosphere and not for the cloud; however, the cloud cooled very quickly as it rose, due to adiabatic expansion and mixing with the surrounding air. Estimates based upon cloud temperature measurements and theory indicated that the cloud temperature did not differ enough from ambient to affect appreciably the computed terminal velocities based on ambient temperatures. For higher yields above about 50 KT this temperature effect on the falling rates probably will have to be taken into account. An example of one set of time-altitude curves derived above is shown in Fig. 1, which presents the curves for a 1950-micron diameter particle.

2. Procedure to Find Size Distributions

The particle size distributions within selected altitude ranges are derived for a given time after burst by using the time-altitude curves. From these curves, the altitudes below which occur chosen cumulative percentages of each particle size are found. The cumulative percentage curves for each size are then plotted on one diagram. For example, Fig. 2

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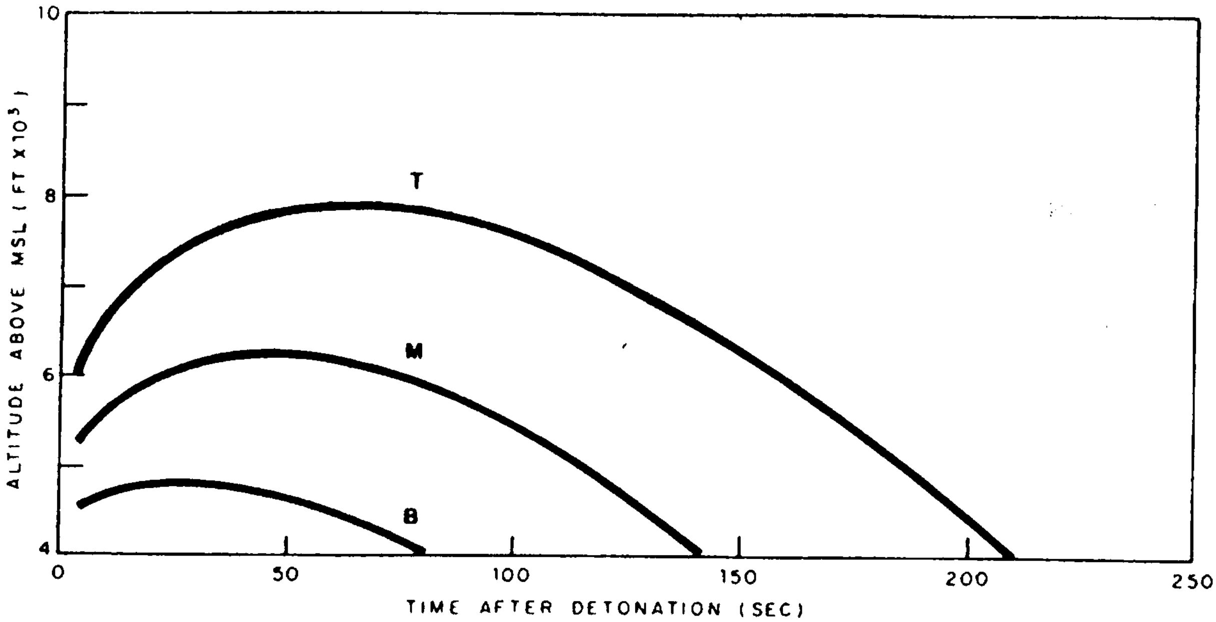

Fig. 1 — Time-altitude curves for 1950 micron diameter particle

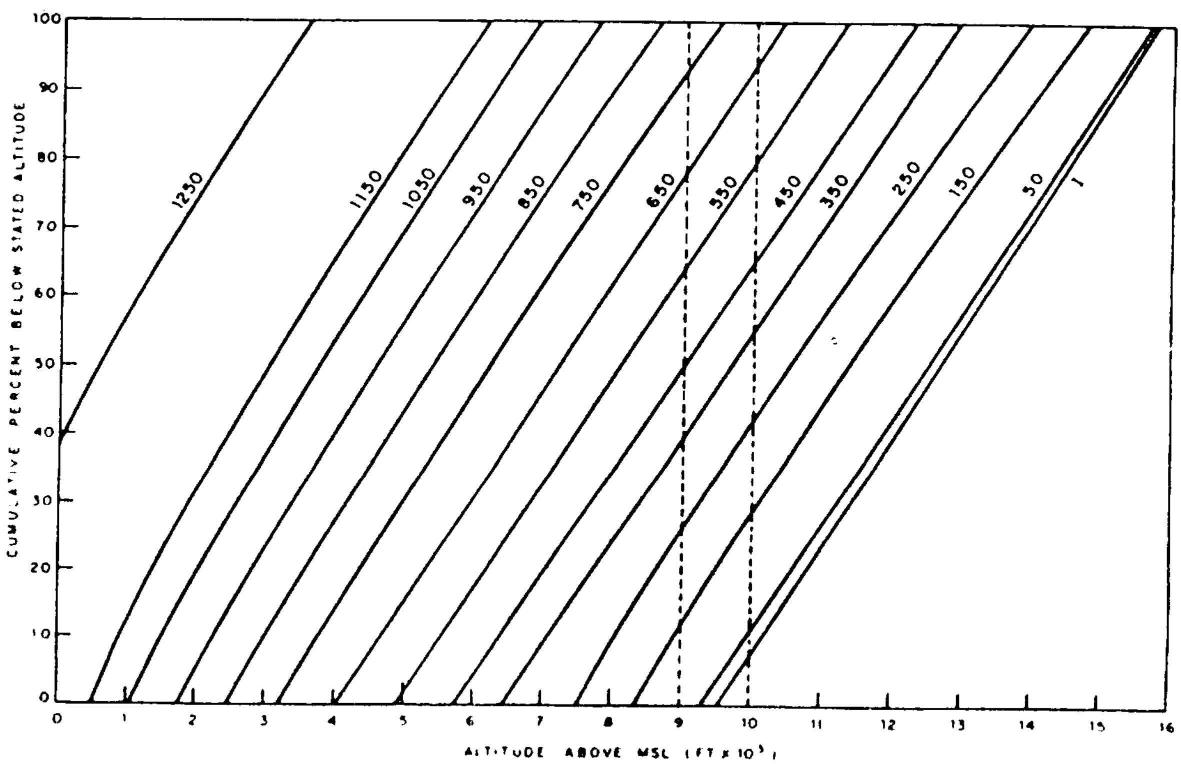

Fig. 2 — Cumulative curves for 300 seconds after detonation

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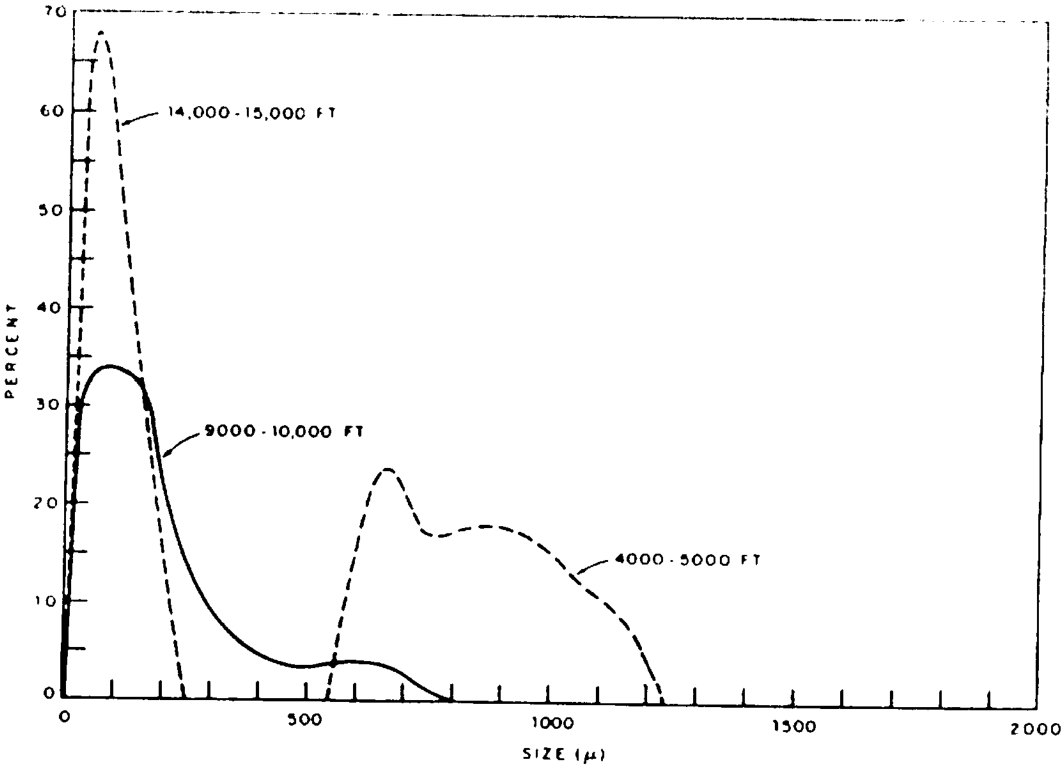

Fig. 3—Size distributions at 300 seconds after detonation

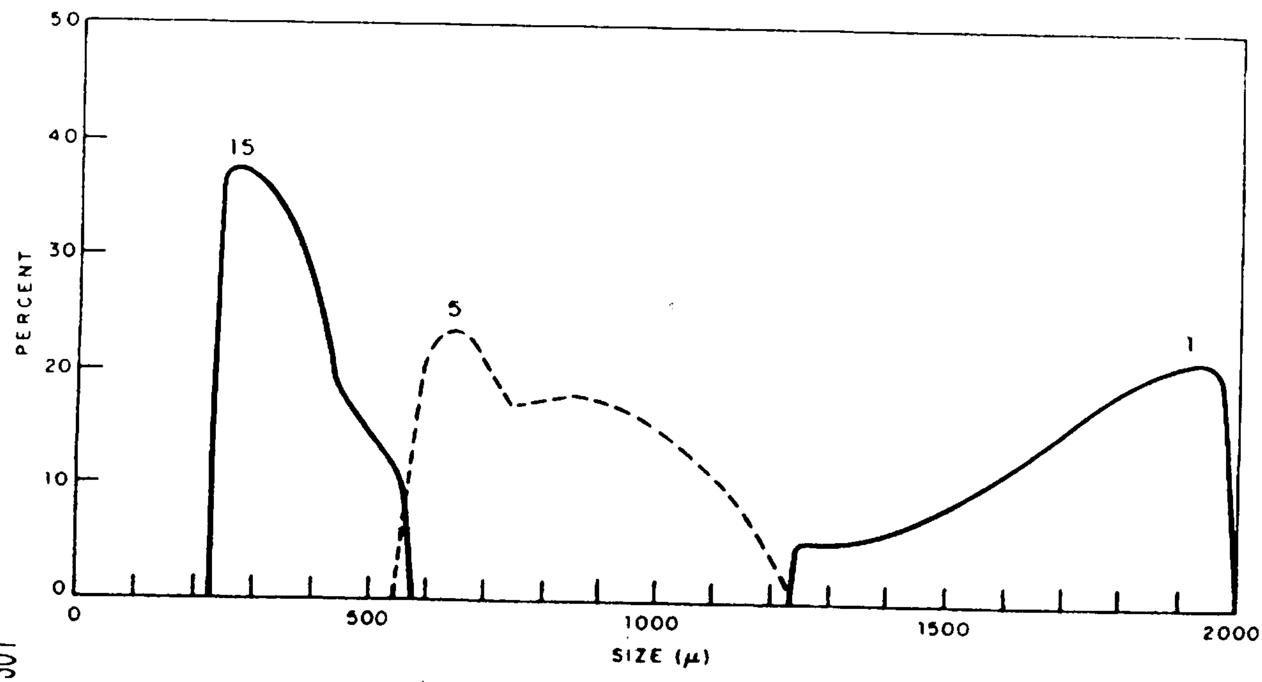

Fig. 4—Size distributions received at the ground at 1, 5, and 15 minutes after detonation

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altitude ranges, indicated by dashed curves. Thus, at 300 seconds after detonation the sizes and size ranges of the particles tend to decrease with altitude.

In Fig. 4 are presented the size distributions within the 4000–5000 msl layer at one, 5, and 15 minutes after detonation. Each of these distributions were derived from a separate diagram, similar to Fig. 2, made for the respective time. The same effect as occurred with altitude is observed with time, namely, the sizes and size ranges of the particles tend to decrease with time. Fig. 4 can be used to find the approximate size distributions arriving at the ground at the indicated times. Distributions arriving at other times between 1–15 minutes can be estimated by interpolating between the given curves.

D. Comparison of Theory with Previous Theory

Most agencies interested in fallout prediction start the gravitational settling of the fallout around the time the cloud has ceased rising, about 5–7 minutes after detonation, instead of within relatively short times after detonation, as assumed by the theory presented in this article. Also, most agencies initially assumed that the fallout was distributed uniformly by size within the mushroom at the time the cloud had ceased rising. Later, this assumption was changed by some of the agencies to one in which the sizes were distributed with altitude; however the fallout was still assumed to start at the time the cloud had reached its maximum altitude. In order to compare the new theory with previous theory, the method developed in this article has been applied to find the respective size distributions received at the ground (within the 4000–5000 ft msl altitude range) at 10 minutes after detonation for the new theory and for a particular previous theory.

This particular theory is based upon the assumption that fallout is distributed uniformly by size within the mushroom at the time fallout starts. Fallout is assumed to start at 5 minutes after detonation, at the time the cloud stops rising. Consequently, the new theory assumed gravitational settling becomes significant almost immediately after detonation, while the previous theory used assumes that it does not become effective until after the cloud has stopped rising. The two resulting distributions are shown in Fig. 5; here the solid curve represents the distribution derived by the new theory, and the dashed curve is for the previous theory. Also, the size range of the "new theory" particles is smaller. If, at the start of fallout, some altitude distribution of sizes had been assumed for the previous theory, then the resulting distribution would have been found to the left of the dashed curve distribution in Fig. 5. Hence, the dashed curve distribution represents an upper size range limit.

From the time-altitude curves, we can easily construct curves showing the time of arrival and cessation of given size particles at 4000 ft msl (at about ground level). In Fig. 6, the solid curves are time of arrival curves for particles starting initially from the top and bottom of the cloud, marked T and B, respectively. For a given size, the B-curve represents this size's time of arrival, and the T-curve represents this size's time of cessation. Particles starting initially from the top at 5 seconds after detonation in the size range from 1200-2000 microns arrive within 100 seconds of each other at 4000 ft msl (between 200-300 seconds after detonation), while particles within the same range starting initially from the bottom arrive within 30 seconds of each other (between 80-110 seconds after detonation). The dashed curves are derived from the

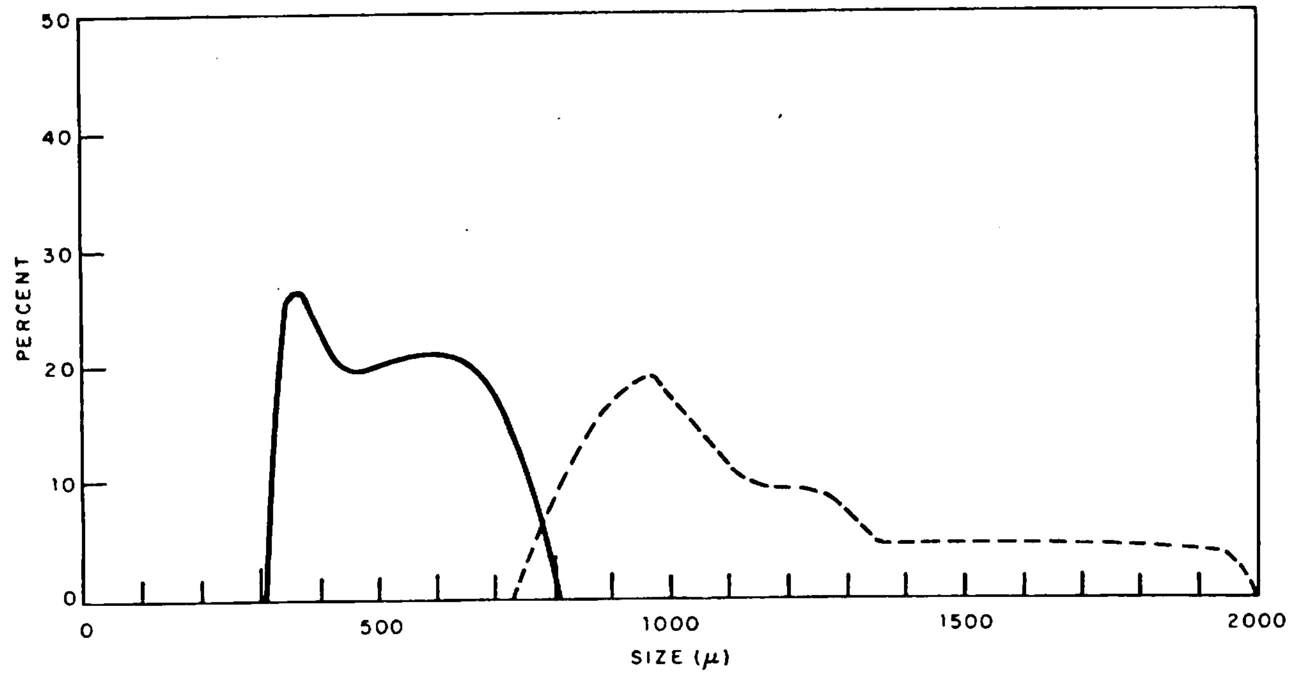

Fig. 5—Size distribution received at the ground for new theory and previous theory at 10 minutes after detonation

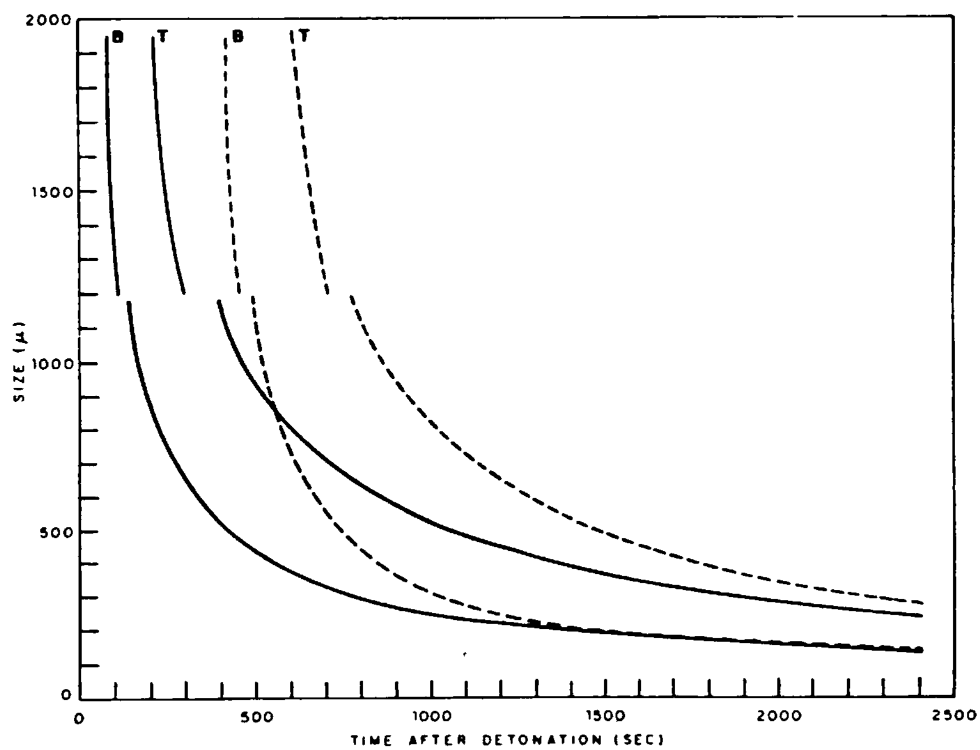

Fig. 6—Time of arrival and cessation curves for particles received at the ground

previous theory mentioned above. Particles of the same size arrive about 300–400 seconds later than particles based on the new theory.

If the time during which fallout is received at a given location is known, then time of arrival and cessation curves can be used to estimate the range of particle sizes received. It may be possible to estimate the size distribution within this range from size distributions calculated for selected times. Due to the finite size of the cloud, particles of the same size arriving from the same altitude will be spread over an appreciable area on the ground. Also, if wind shear is present, the particles arriving at the ground will be spread over a larger area. In addition, the various sizes arriving at the same time will have different impact areas because of their varying trajectories. However, the distribution of sizes as measured at given locations on the ground may not differ appreciably from that predicted due to the overlapping of the areas. The effect of wind shear will not be appreciable at short times after burst since the particle trajectories will not differ greatly in altitude. Also, at long times after burst it will not be appreciable since the range of particle sizes received at the ground will be very restricted, and hence the trajectories will not differ greatly.

The two theories can be compared on the basis of the altitude distribution of sizes at a selected time after detonation. Thus, for 300 seconds after detonation, Fig. 7 shows dashed lines for sizes starting at the top and base, respectively, for the new theory, and solid lines for the previous theory. Note that the dashed lines represent a linear variation of particle size with altitude. According to the new theory, there are no particles greater than 1200 microns above the ground at 300

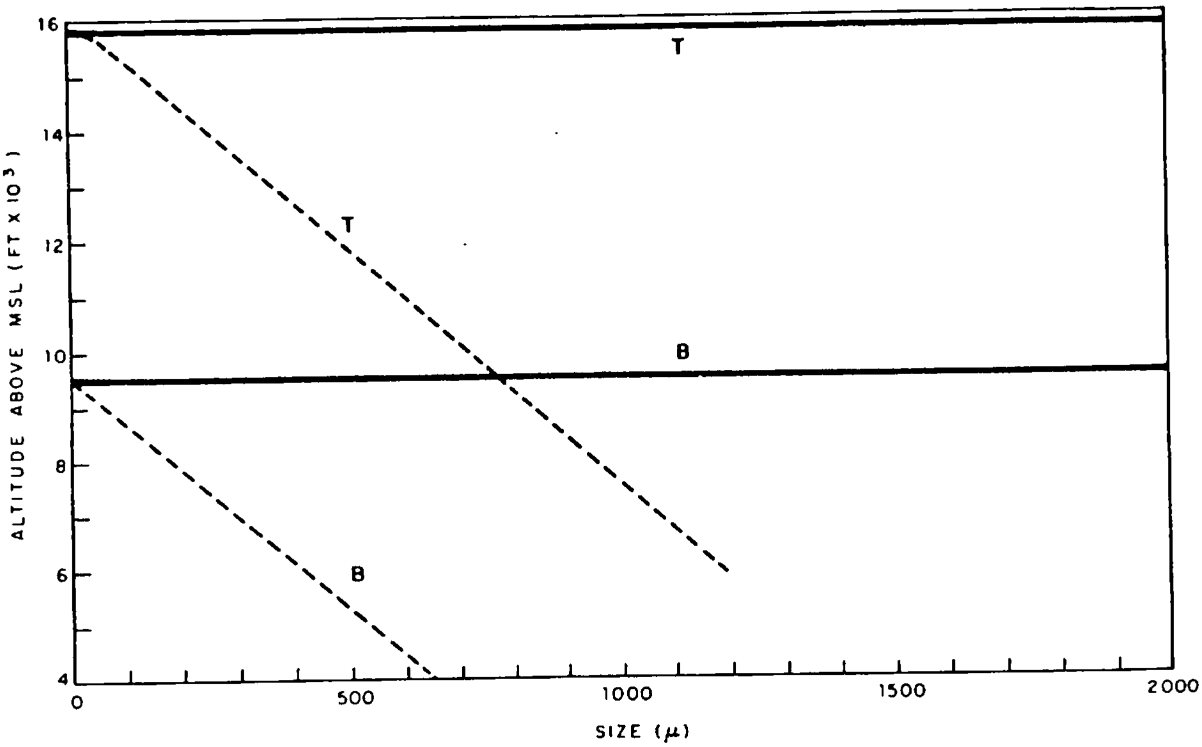

Fig. 7—Altitude distribution of sizes at 300 seconds after detonation for new theory and previous theory

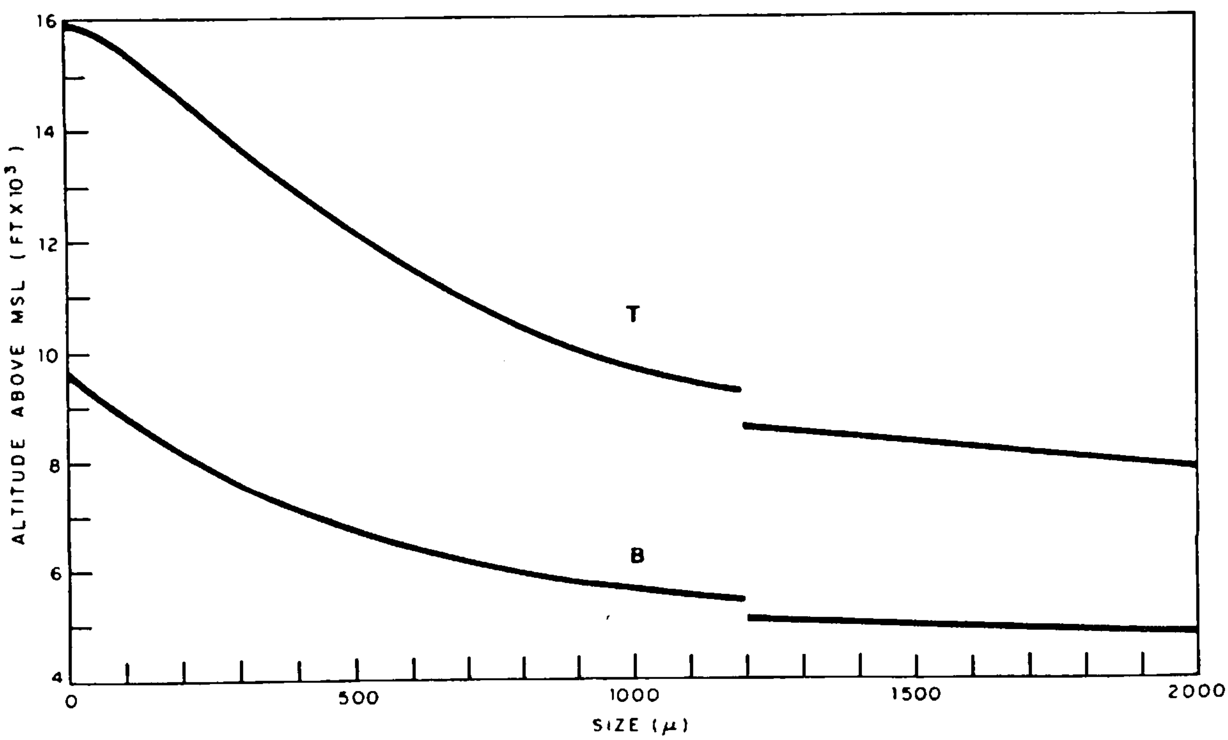

Fig. 8—Maximum altitude reached by particles

seconds after burst, while the previous theory results in particles of 200 microns at 15,800 ft msl. In Fig. 8, derived from the new theory, is presented the maximum altitude reached by a given size for particles starting initially at the top and base, respectively. All particles starting from the top in the size range from 1200–2000 microns reach within 400 ft of the same maximum altitude (8200 ft msl); all particles starting from the bottom in the same size range reach within 100 ft of the same maximum altitude (4900 ft msl).

Particle size distribution data are lacking for JANGLE-Surface, but field measurements are available which give the distribution of radioactivity on the ground. Therefore, as a further check it is planned to compare the intensity contours derived using the two theories with the actual intensity contours.

E. Discussion

The theory presented is believed applicable for close-in fallout (for times up to 20 hours after detonation). One can find the trajectories of the fallout particles by using the time-altitude curves together with wind and cloud geometry data. Consequently, the theory can be checked by measuring the time of arrival, size distribution, and characteristics of fallout at given locations. The theory does not give the number of particles of different sizes comprising the distributions. This information could be assessed indirectly from field intensity data provided that the relation between particle size and radioactivity were known. As a result, the size distribution in the cloud could be given in terms of absolute values. The total activity distribution in the cloud should be very variable, especially for short times after detonation.

In order to apply and check this new theory and to learn more about the fallout mechanism, the following data is needed for each test:

a. Preshot soil size distribution and composition.

b. Time-altitude data for top and bottom of the cloud.

c. The number, appearance, size, shape, and composition of active particles arriving at selected locations within known time intervals.

d. Relation between size and activity of particles.

e. Rawinsonde data extending from ground up to the maximum height of the cloud.

f. Fireball and cloud temperature data from detonation until cloud has cooled to ambient.

F. Conclusions

A new theory is presented which takes into account the fallout phenomena from the time of detonation to the time the mushroom cloud stops rising. The theory, is based on the assumptions that most of the active fallout is created at relatively short times after detonation and that the main effect moving the fallout is due to the rise of cloud, gravity, and horizontal winds; it is believed applicable for close-in fallout (up to 20 hours after detonation) resulting from all nuclear yields. The theory has been illustrated for a low yield land-surface burst – the resulting size distributions should be more marked for higher yields, since the size, altitude, and time interval range should be greater. Also, the maximum altitude and time of arrival and cessation on the ground were derived for given particle sizes. The trajectories of these particles can be found by using wind and cloud geometry data.

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APPENDIX D

Empirical Determination of Fallout Cloud Model Parameters

James W. Hendricks

Cloud model parameters are quantitative representations of the cloud shape, the cloud composition and the cloud activity. For example, the cloud shape can be described by the height of the cloud and cloud diameter at specified altitudes; the cloud composition may be described in terms of particle size distributions at specified points within the cloud, and measures of activity can be provided throughout the cloud. These parameters usually refer to the cloud a very short time after the shot time and this reference time is an important parameter. A complete set of cloud parameters constitute a cloud model. Customarily, a cloud model is employed to predict a distribution of activity on the ground at one or more intervals throughout and after the fallout period. The validity of a cloud model is usually tested by the comparison of predicted activity contours with measured activity contours. Discrepancies are eliminated by the modification of doubtful or unknown cloud parameters. In the past, ignorance of most cloud parameters has left us free to vary any or all of them in order to eliminate errors in prediction..

The approach described here is to determine cloud parameters exclusively by the analysis of collected fallout. The procedure consists of retracing the paths of individual particles from the location and time of collection to their positions in the cloud at one or more reference times.

At various sampling stations particles have been collected with the NRDL incremental fallout collector. The particles are being measured and

raw data is available in the form of particle size distributions varying with time at each sampling location. The data is put on IBM cards and the individual particle trajectories in reverse are calculated with the digital computer at the Naval Post Graduate School at Monterey. For each particle size, for each time interval of collection, at each station, a unique point in the cloud is determined. For each point so determined, the concentration of particles in the cloud is computed from the concentrations measured at the collecting station. For a sufficiently large number of unique measurements on the ground, all cloud parameters associated with particle deposition may be determined for any specified reference time.

Note that cloud shape and cloud composition parameters are determined independently of individual particle activity, activity distributions on the ground, and cloud model activity parameters. This illustrates the principal advantage of this approach to the determination of cloud model parameters. It is possible to discriminate between influences of the individual parameters. For example, there is no danger of modifying the cloud height to compensate for an erroneous vertical distribution of activity. Mr. LaRiviere, whose paper has been presented, and Mr. Harry Chan of NRDL are studying the relationship between particle size and activity and it is hoped that their data may be employed in the independent determination of the cloud model activity parameters. The validity of these determinations may then be tested by the comparison of activity contours, computed from the cloud model, with measured activity contours on the ground. The cloud shape and composition parameters have been derived exclusively from incremental collector data and their validity may be tested independently by the comparison of computed mass contours with measured mass contours determined from total collectors.

We know very little about the manner in which particles rise to their positions within the cloud. Mr. A. Anderson of NRDL is conducting a theoretical investigation of the subject. At present, it is assumed that particles are falling at terminal velocity at all times and at no time is their movement influenced by the detonation. Referring to the figure, the altitude of a particle is plotted against time. The dotted curve indicates actual altitude of the particle from shot time to Time T_3. The particle rises under the influence of the detonation, reaching its maximum height at Time T_2, and by Time T_3 all components of its vertical motion due to the detonation have vanished. The solid curve indicates the change in altitude of a hypothetical particle with the same time of arrival T_a. If the cloud parameters determined actually describe a cloud at some reference time, after which all particles are no longer influenced by the detonation, then no error is involved in the description. There is no way of knowing, of course, when all particles are no longer influenced by the detonation. If time T_1 is chosen as a reference time and the path of the particle described by the diagram is retraced, the altitude of the particle at reference time will be given as H_3 when in fact the altitude was H_1. Between T_1 and T_3 horizontal displacement of the particle will be computed employing incorrect wind data.

At present there is no way to eliminate this error. However, since the model parameters have been determined by retracing particle trajectories, no discrepancies need exist no matter what reference time is chosen. In fact, a hypothetical shot time cloud, which of course did not exist, can provide a perfectly valid cloud model. This hypothetical cloud is higher than the actual cloud and may be slightly asymmetrical due to the errors in horizontal displacement. The significance of these errors is

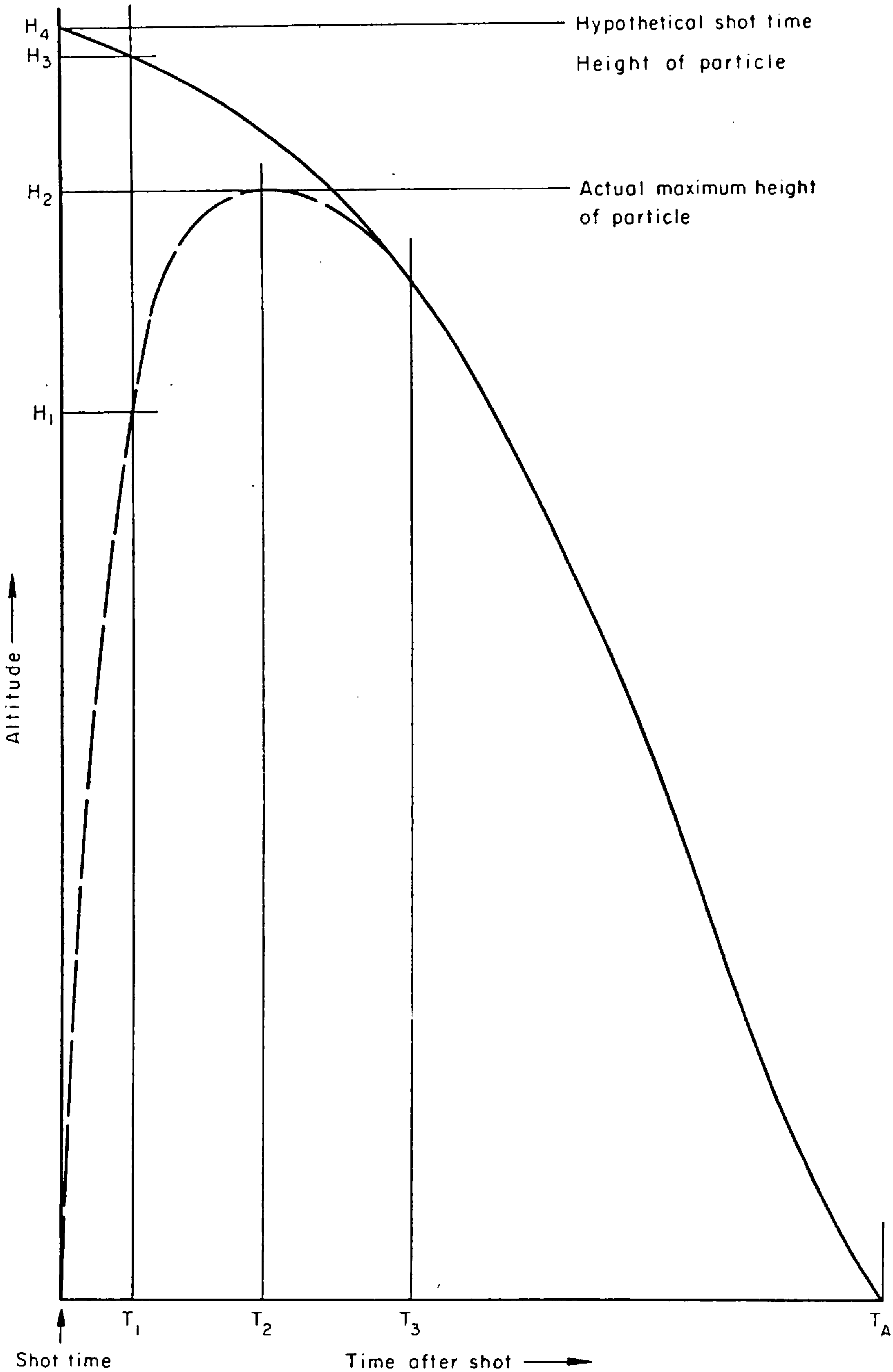

Fig. 1 — Comparison of particle height with time

minimized by the fact that the cloud rise-time of the true cloud is relatively small.

In the current analysis of REDWING data, terminal velocities are calculated employing the equations for the regions of streamline, intermediate, and turbulent flow as given by J. M. Dalla Valle. At first, great difficulty was encountered in the application of these equations. The difficulty is inherent in the use of these equations to compute terminal velocity of irregular particles. There are many ways in which a measure of size for irregular particles may be defined. The measured particle size must be distinguished from the effective particle size, and in fact, the measured particle density must be distinguished from the effective density. For simplicity, consider an irregular particle which falls in the region of streamline flow at all altitudes. The equation for terminal velocity in the region of streamline flow is

$$V_s = K_s \frac{\sigma - \rho}{\mu} d^2 \qquad (1)$$

Here V_s = particle terminal velocity

σ = particle density

d = particle diameter

ρ = density of the air

μ = viscosity of the air

K_s = an empirically evaluated constant.

Suppose that the particle, at a given altitude, falls at terminal velocity V_s and that density and viscosity of the air at that altitude are respectively ρ and μ. Thus, for all cases in which the equation yields the correct terminal velocity, a given particle "diameter" defines a unique particle density and vice versa. Any combination of particle size and density which

yields the correct terminal velocity may be termed a valid effective size and effective density combination. The measured size is effectively specified by the apparatus and procedures employed. The apparatus and procedures employed are presumably chosen for the convenience of the investigator. There is no necessary relationship between the measured size and the measured density. The physical significance of a measured density may be questioned for very rough or porous particles. We must conclude that, for irregular particles, the measured size and the measured density alone are insufficient for the determination of a valid effective size-density combination. The determination of a valid effective size-density combination appropriate to a measured size-density combination must be independently determined if measured size-density data is to be useful. In fact, the measurements obtained are of value only as a classification label until such time as they are related to a valid effective size-density combination.

Errors introduced by using the wrong effective size and density for a given measured size and density are cumulative with altitude so that at high altitudes obvious errors occur. Clouds thousands of miles in diameter are obtained. Consideration of obvious errors in the calculation of particle trajectories and an analysis of the variation in particle size distribution with time of arrival make it possible to relate measured size density to effective size density by a tedious process of elimination. The measured size employed is obtained by photographing the particle, as collected on an incremental collector tray, enlarging the photographs ten times, and determining the diameter of the largest circle which can be inscribed in the area representing the particle.

If the measured size of 110 microns is employed as the effective size,

it was found, in the analysis of Tewa fallout, that an effective density of 1.4 is required. If a measured density of 2.36 is employed as the effective density for particles in the measured size classification of 110 microns, it was found that the corresponding effective size must be 90 microns. Observe that for a density of 2.36, which is a reasonable value for the measured density, the inscribed circle method of measuring actually yields a measured size too large to be employed as the effective size.

In general, the relationships between the effective parameters and their corresponding measured parameters must be defined with reference to the procedures and apparatus employed in measurement and with reference to the calculation system employed. In this case, the calculation system is the set of terminal velocity equations as applied in each of the specified flow regions. These equations were developed for spheres and numerous experiments have been performed which testify to their applicability in this case. Thus for spheres, we must expect that the effective diameter is the measured diameter and the effective density is the measured density.

In this analysis time variation of upper wind data is considered. Space variation and vertical components of wind velocity are not. The work of E. A. Schuert of NRDL indicates the possibility of error in this simplification and it may be necessary to take these into account in the future.

The analysis of Tewa incremental collector data is in progress, and will be reported on completion.

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APPENDIX E

Employment of Time and Space Variable Winds,
Including Vertical Motions, on the Analysis of Particle Trajectories

E. A. Schuert

There is still some question as to the northerly extent of fallout deposition after shot Bravo at Operation CASTLE. It was the first megaton device detonated wherein a smattering of knowledge was obtained at distances greater than fifty miles. The application of time and space variation of the winds in analyzing the forecast fallout was first attempted after this detonation in the hope of defining the pattern. Unfortunately, the meteorological data were poor and this, combined with a lack of measured data on the distribution of fallout, leaves the question unsettled to date.

We know at this time that both time variation and space variation of the winds can be significant, and there has been added by some the less-understood complication of vertical motions. I wish to present the results of my analysis on the shot Zuni Winds at Operation REDWING, wherein all three of these parameters were considered. I found at the test site that the definition of the perimeter of the fallout pattern and the axis of the "hot line" were excellently forecast by making several assumptions about the distribution of activity in the cloud and employing only corrections for time variation of the winds. This was the case for three shots out of the four documented, namely Tewa, Flathead, and Navajo. The assumptions made were that (1) the majority of the activity was located in the lower 1/3 of the mushroom and consequently the height lines from this layer would define the hot line, (2) the optical diameter of the mushroom defined the radiological cloud, and (3) the contribution of fallout from the lower

2/3 of the stem could be ignored. A complete description of the model parameters used can be found in the NRDL report now under publication titled, "A Fallout Forecasting Technique with Results Obtained at the Eniwetok Proving Ground."

However, for shot Zuni the forecast fallout, based on time variation only, deviated from the measured pattern by approximately 30 degrees in Azimuth, and, in fact, left two of our sampling ships high and dry, so to speak. It is the analysis of this shot that I wish to discuss at this time. I plotted the height lines from 60,000 ft. These were constructed by computing the trajectories from this originating altitude of four particles: 75, 100, 200, and 350μ in diameter. An altitude of 60,000 ft was chosen, for our scaling curves indicated this altitude to lie in the base of the mushroom and, consequently, the resulting height line would define the radiological axis of the pattern. For matters of comparison, the following plots were made: (2) use of shot-time Bikini winds only, (b) use of shot-time Bikini winds including time variation, (c) use of time and space variation and (d) use of time and space variation including vertical motions.

Although the meteorological data available were far from ideal they certainly were much better than we had at Operation CASTLE. These data were available for use:

Constant-level Isogon-Isovel analyses of the wind field for 10,000 ft, 16,000 ft, 25,000 ft, 30,000 ft, 40,000 ft, 50,000 ft and 80,000 ft at H-3 hrs, H+9 hrs, H+21 hrs and H+33 hrs. In other words, 12-hour continuity in five- to ten-thousand-foot altitude increments, all analyzed from a sparsely populated station network. These data were obtained from the Task Force Weather Central:

Vertical motion analyses as computed by the weather network under the direction of CDR Dan Rex for 2,000 ft, 10,000 ft, 20,000 ft, 30,000 ft, 40,000 ft and 50,000 ft at H-3 hrs, H+3 hrs, H+9 hrs, H+15 hrs, H+21 hrs and H+27 hrs or 6 hour continuity in 10,000 ft altitude increments.

As well, the measured winds aloft at 3 hr intervals were available for the Bikini area.

I do not care to defind or criticize any of these data at this time, I simply say this is what was available to me, and the trajectory computation were made on the assumption of their validity.

The plotted trajectories were then computed based on the average wind in 5,000 ft layers using 3 hour continuity. Data points were obtained from the source material by using linear interpolation in time and space. The two exceptions to this were (one) rather than interpolate for winds above 50,000 ft from the constant altitude charts, the measured Bikini winds were used, and (two) since no vertical motion computations were made above 50,000 ft, the values were assumed constant from 50,000 ft to 60,000 ft.

The job was a tedious one and became quite slow when the addition of vertical motions were included in the analysis, for they too vary in space and time. Corrections for vertical motions were included in the analysis by correcting the computed falling speed of the particle in question in each layer. Such corrections were significant in magnitude for shot Zuni, being as great as 50 per cent in some cases for the 75μ particle at the higher altitudes.

Figures 1 through 3 show the field results obtained for the three shots where agreement was considered satisfactory. Figure 4 is the result of

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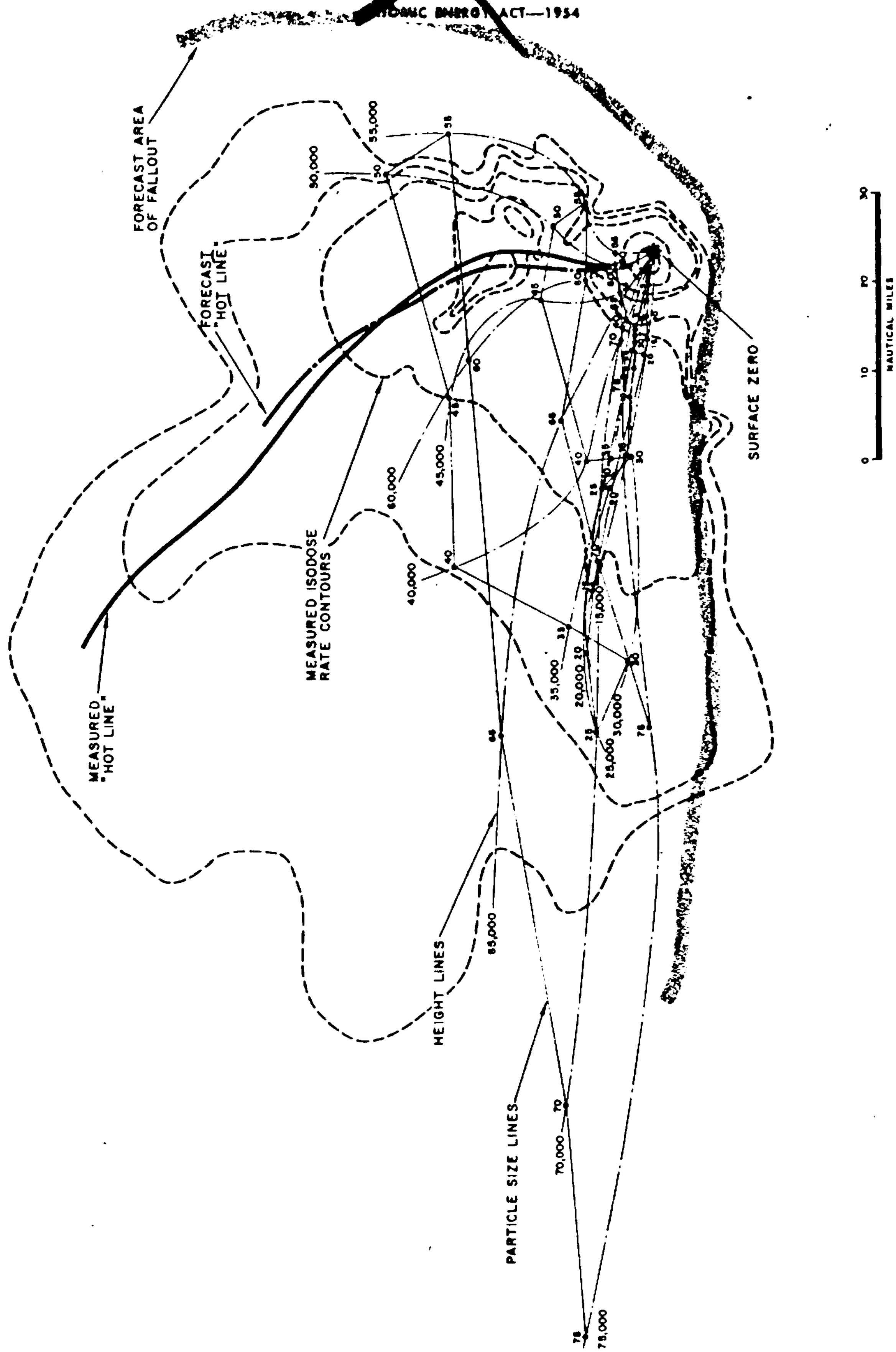

Fig. 1—Comparison of predicted and observed fallout pattern for shot Tewa

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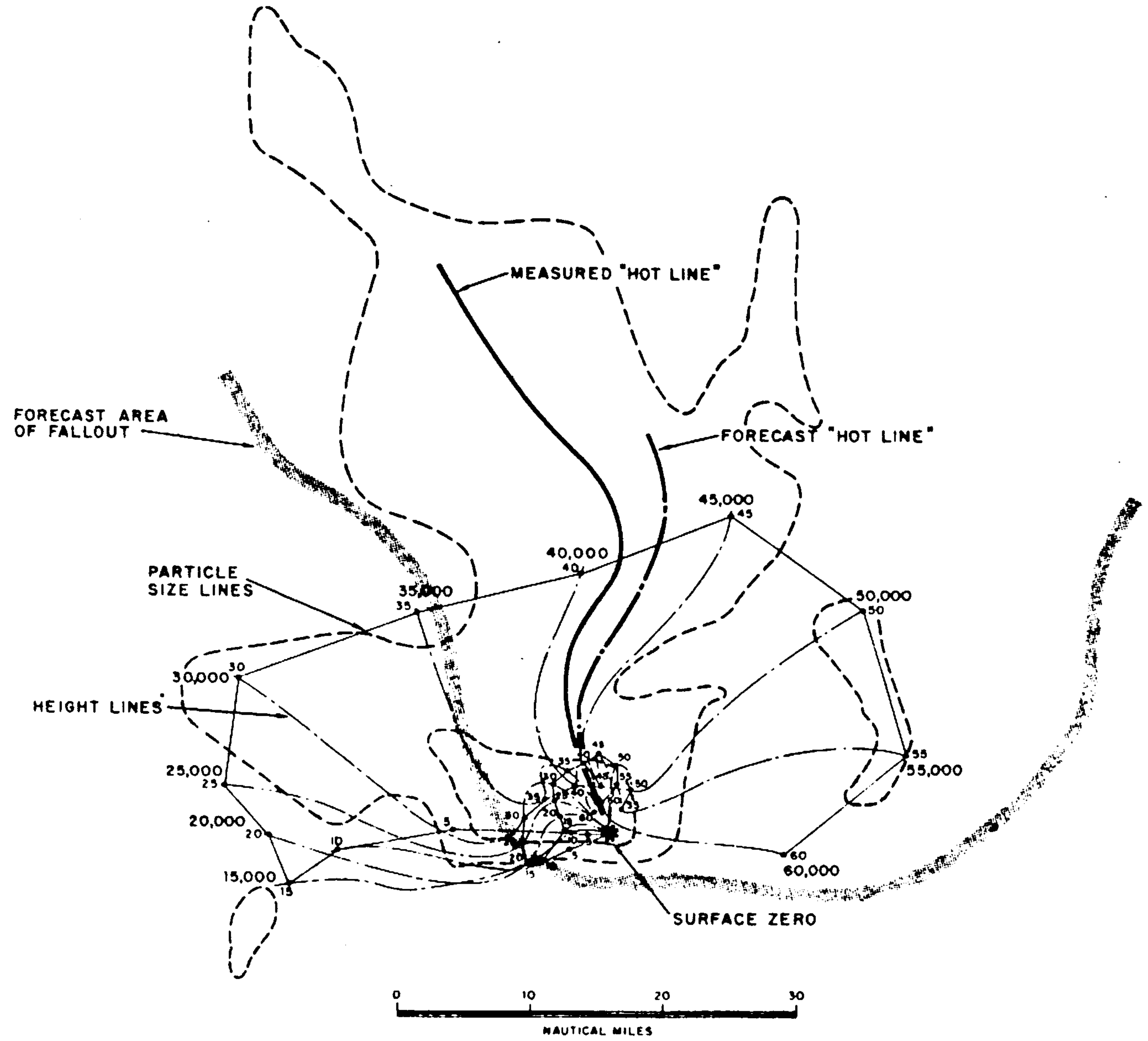

Fig. 2—Comparison of predicted and observed fallout pattern for shot Flathead

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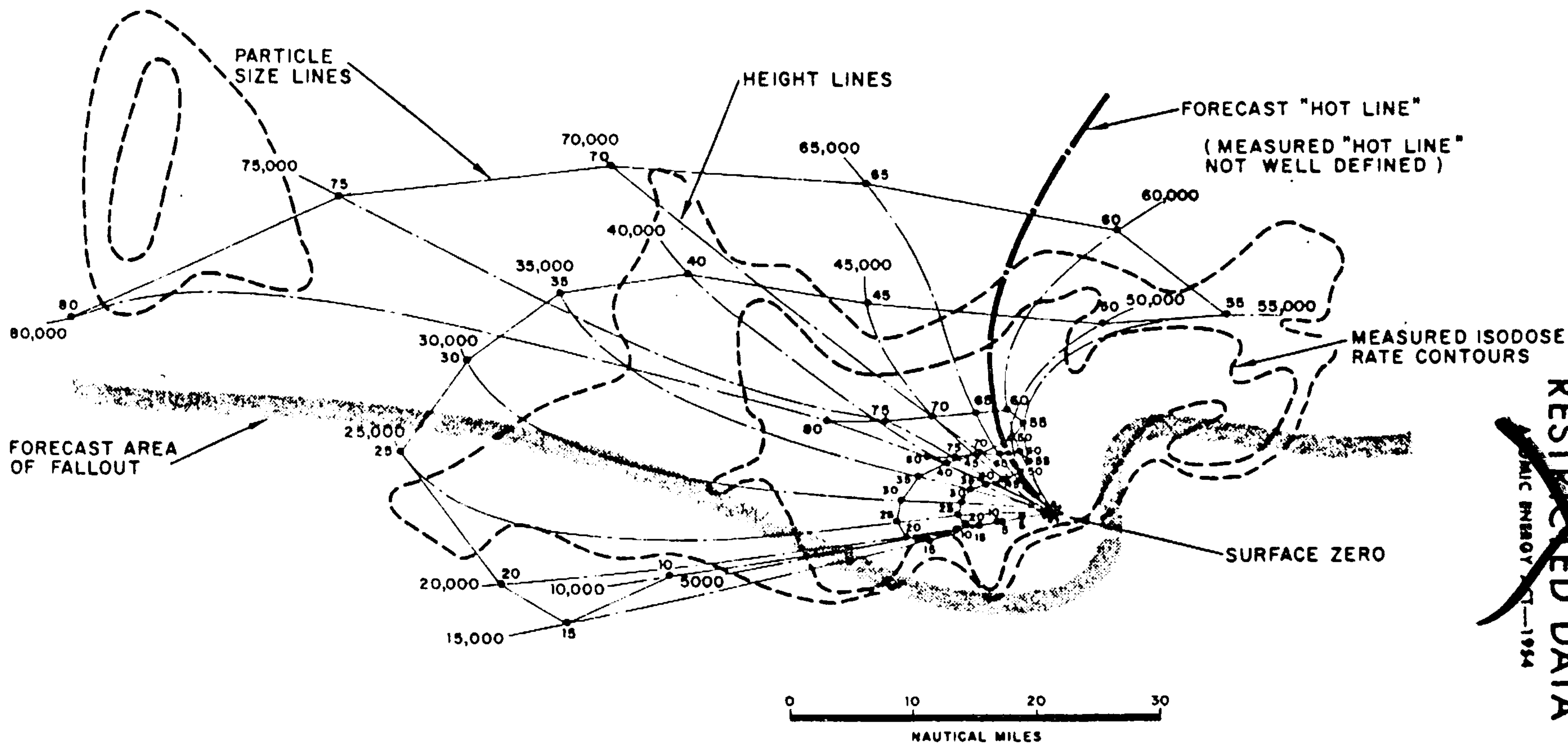

Fig. 3—Comparison of predicted and observed fallout pattern for shot Navajo

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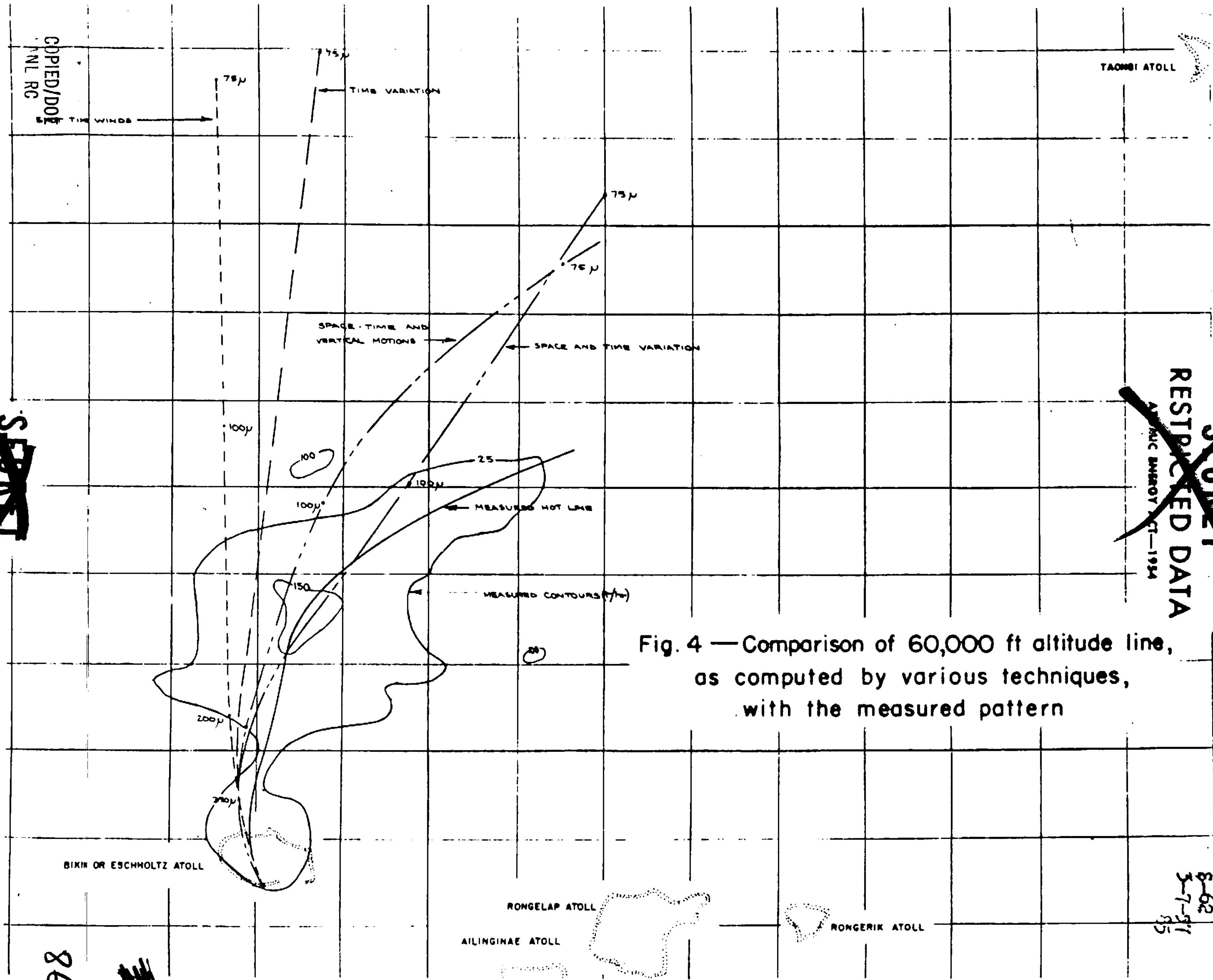

Fig. 4 — Comparison of 60,000 ft altitude line, as computed by various techniques, with the measured pattern

the various forecasts employing different meteorological parameters on the shot Zuni analysis, and deserves some discussion. As you can see, the employment of time variation alone helps little in improving the fallout forecast. However, inclusion of time and space variation resulted in most satisfying results. When vertical motions were considered, the forecast became somewhat less agreeable with that measured. Their use did change the time of arrival by approximately 15 per cent; however, this has not been checked against measured data, should the opportunity exist.

Unfortunately, from this analysis nothing can be said about the possible inclusion of vertical motions in such analyses; until we know more about their existence or non-existence, and check computed values with measured, I am tempted, on the basis of this analysis to suggest they be ignored in any fallout forecasting technique used at this time.

APPENDIX F

Studies of the Weather Bureau Research Station

P. W. Allen

The Weather Bureau Research Station was established in June 1956, for the purpose of improving the forecasting of weather phenomena, particularly winds, at the Nevada Test Site. The studies cover both the small-scale, low-level phenomena and the upper level feature. The latter are of particular interest to those of us in the fallout business, and include studies of the variability of the wind, relating variability to other, somewhat more easily predictable quantities such as wave position and speed. The variation with both time and space is being considered. Local peculiarities are being studied and attempts are being made to arrive at useful objective forecasting techniques.

The most promising work to date in forecast improvement has been through the use of charts representing the mean motion of relatively thick (10,000 feet or more) layers of the atmosphere. The average 6-hour change of direction in the layer between 15,000 feet and 25,000 feet for 46 cases in February and March 1957 was 11.4 degrees, while the corresponding average change in the 500 mb (near the 18,000-foot level) point wind was 15.4 degrees, or 27% larger. This mean layer wind is obtained by letting the rising pilot balloon or rawinsonde balloon integrate the air motion as it rises in the same way, only in reverse direction, that a particle of debris is influenced by the wind as it falls. The direction and speed of the wind in the layer are obtained from the vector joining the horizontally projected positions of the balloon at time of entering and time of leaving the layer.

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The analysis of mean layer winds is being done using isogons (lines of constant direction) and isotachs (lines of constant speed). Forecasting is accomplished using conventional techniques plus the extrapolation of the isogons and isotachs. Obviously, since the variation of direction is so much less for the mean layer wind than for the point wind, the forecast mean layer wind should come nearer verifying correctly. To test this, two forecasters daily predicted mean layer winds for the 15,000-to 25,000-foot layer and two other forecasters predicted the 500 mb point wind for four stations: Ely, Las Vegas, Yucca Flat and Tonopah. Station operations prevented preparation of 6-hour 500 mb wind forecasts, but comparison of the systems is possible for 12-hour periods. The following table gives the average error in direction only, for the two procedures, including the error from use of persistence as a forecast for the same cases. Only 36 forecasts are reported.

	6 hours	12 hours	24 hours
Av. 500 mb Forecast Error		23°	33°
Av. 500 mb Persistence Error		26°	38°
Av. 15-25M Forecast Error	7°	11°	
Av. 15-25M Persistence Error	12°	16°	

This test is being run under ideal conditions so far as time is available to the forecaster. The reported errors are only for February and do not cover a very wide range of conditions. Because of the small sample, we have used only arithmetic averages. The test is still running and prior to the next NTS operation, it is planned to have the results in more refined form, covering a wide range of situations, with some indication of forecast reliability relative to position of the verification station in the wave pattern. Verification of wind speed is also better under the mean layer wind system, but the results are not so noteworthy as the

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direction results.

This system should be even more valuable during the summer, when speed variation is diminished and small-scale direction variation is a maximum. The Research Station has not tested it on a summer situation yet but intends to do so as soon as possible.

Other projects under way at WBRS include tests of numerical progs as issued by JNWP, Suitland, Md., for predicting spot winds, and studies of local winds including drainage currents, channeling and upslope effects.

APPENDIX G

NEW UPPER WIND MEASUREMENT TECHNIQUES

A. D. Anderson

There are two developments in instrumentation for measuring upper winds that are of interest for fallout prediction.

First, is the Transosonde System,(1) in which wind data is derived by tracking transmitters on constant-pressure-surface balloons. The feasibility of this system has been completely demonstrated, and the Navy will soon start operational flights across the Pacific, and later will follow flights across the Atlantic. The Transosonde system as presently employed consists of a 39-foot plastic balloon, a gondola containing transmitter, power supply and ballast, and control devices — totaling in weight about 600-700 lbs.

Tracking is done by means of a network of high-frequency direction finder stations, most of which are in the U.S. The trajectory of the balloon is derived directly from the tracking data, and from this is given the wind velocities along the path of the balloon. The present system was developed to map out the large scale features of atmospheric flow at high altitudes; however, a requirement does exist for detailed knowledge of wind field variation between the sounding stations comprising the network used at the Pacific Proving Ground and Nevada Test Site. The present system can be reduced in scale and the concept readily applied by using instrumentation consisting of a small plastic balloon, a radiosonde, GMD-1A for tracking, and a simple ballast system. The plastic balloon is partially inflated on the ground with the proper amount of gas so that it acquires its full

volume at the predetermined altitude. Even without a ballast system the balloon would level off and continue on approximately level flight for some time; however, by using a simple ballast system flight can be made for many hours in duration. H. Mastenbrook and the author made several flights of 3-4 hours duration by using freon in a container which allowed simple evaporation to take place at a rate controlled by the size of the opening. The GMD-1A gives elevation angle and azimuth angle data every six seconds; the height of the balloon is determined from the transmitted pressure data. This information allows wind data to be readily derived from the constructed trajectory. Small-scale variations in flow may be determined, fine features that could be determined by no presently available equipment. In addition, errors in velocity determination due to the errors in tracking can be minimized by treating the wind velocity data statistically. Thus, if the data for one minute were used, 5 independent wind vectors could be extracted. The longer the period of averaging used, the greater the accuracy of the derived wind vector. Such a system can be employed not only to give the details of the flow between regular stations of the rawinsonde network, but it can be used also to give shot prediction.

Thus, if balloons were regularly released before shot time and followed at one or more levels, the actual space and time variation in the wind field taking place could very readily be determined in a quite accurate manner.

Another new development is the use of window (chaff) ejected from rockets and tracked by radar to measure high altitude winds.(2) Due to the error in measuring pressure the present rawinsonde system is not considered operational above about 60,000 ft. Even if the pressure measurement were perfect, however, the line-of-sight tracking employed limits most flights

to below 80,000 ft. In winter, when the data is most needed, flights are limited to below 40,000 ft in strong wind conditions. It is apparent that if high altitude winds are desired above 100,000 ft, rockets will have to be used to carry the target to be tracked. The system mentioned above was proposed by the writer in response to a requirement from the Commander/JTF-7 in 1954 for a reliable method of measuring winds up to 150,000 ft in the Pacific Proving Ground area. The feasibility of the proposed system was demonstrated by tests made at the Naval Research Laboratory, and later tests made by ONR have successfully tracked window at altitudes above 160,000 ft. One disadvantage to the use of window is that it results in wind data for a limited altitude range only due to its dispersion. The writer has suggested using non-dispersing targets such as metallized cloth to get continuous wind soundings down to the ground. The ideal target would be a sphere, since it would give the same echo return regardless of its orientation. It is proposed that a metallized balloon be used. Silvered balloons 3-ft in diameter have been tracked by radar at ranges up to over 400,000 ft. Recently the NACA announced an assembly which suits the requirements. The NACA has developed sub-satellites which will be ejected with the primary earth satellite. These 20-inch diameter metallized plastic spheres will be automatically inflated by the cartridges they enwrap. The total weight of this assembly is less than one pound. The balloon could be inflated with a lifting gas to control its rate of descent.

The use of such a system as the proposed rocket-radar-window system would be invaluable for determining when to fire the weapon at the Proving Ground. During the last Redwing tests the system using window was used to give spot checks on the forecasted winds. The system uses small, relatively inexpensive, and easily handled rockets, and readily available radar

to get winds in an automatic manner. Wind data can be secured from any desired altitude up to above 200,000 ft within a few minutes at the most. The system thus gives data not available using any other system, operational or research, and it is believed that it meets all the requirements imposed for wind velocity measurement in the test operations. Actually, using the proper combination of rocket-target and tracking, it is considered feasible to measure winds at any altitude in the atmosphere where meaningful air circulation exists.

References

(1) "A New Upper Air Data System—The Transosonde," A. D. Anderson, H. J. Mastenbrook. Bull. AMS Vol. 37, pp. 342-350.

(2) "Experiments Using Window to Measure High-Altitude Winds," A. D. Anderson, W. E. Hoehne, Bull. AMS., Vol. 37, pp. 454-457.

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APPENDIX H

Surface Fallout Measurements

T. Triffett

Foreword

Such measurements divide into two broad classes, those made on cloud surfaces and those made on water surfaces. In the latter case the measurement situation is complicated by the settling and dissolving of the fallout material. A concerted effort is being made, using the comprehensive set of data obtained at Operation REDWING, to assess the errors inherent in both classes of measurements quantitatively. Thus far the sources of error have been isolated and defined; these are described below.

In general the errors which enter into water surface measurements are more numerous and larger than those which enter into land surface measurements, and additional definitive measurements are required for this case. Consequently, contours constructed from PP4 events may be in serious error in those regions determined by aerial and oceanographic survey only. After the REDWING data has been reduced and correlated, such that land equivalent fallout in such regions may be computed from several different collection and measurement methods, it should be possible to arrive at numerical estimations of the error involved.

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1. Introduction

Since our senses cannot perceive the radiations associated with nuclear fallout, and may not be able to distinguish its deposition from some natural phenomenon, we are particularly dependent on the measurements we make. So far we have been able to plan these measurements in advance for any actual event, pre-position our instruments, and analyze the results later. These are the kinds of measurements which will be discussed in this paper; they provide the information required for prediction.

It should be recognized, however, that other measurements may be required for the assessment of a real situation. In many cases it will not be possible for us to place our instruments in advance, since both the type and location of the detonation will be unknown before the fact. Either from the point of view of an outside observer, who would like to know what measurements to make and where to make them in order to define and characterize the affected area as quickly as possible, or from the point of view of an inside observer, who would like to be able to predict the nature and extent of the total radiological event from his limited observations, conditions are quite different from the experimental situation. From this it may be seen that the ultimate objective of measurements made under experimental conditions is not only to define fallout processes for prediction purposes, but also to determine the measurements which should be made in any real situation.

Adequate definition of fallout processes for any set of experimental conditions depends on obtaining sufficient data for the evaluation of models, the construction of mass, fraction of device and radiation contours, and characterization of the material. The specific measurements required for

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each of these will be discussed below; but it is interesting to observe at this point that, in general, the first requires time-dependent fallout measurements, the second, total fallout measurements, and the last laboratory analyses of samples. When deposition occurs on a solid surface such as an extended land mass, measurements made following cessation represent the total fallout which arrived; if deposition occurs on a water surface, however, this is not the case. Additional measurements must then be made to determine how much material has settled below the range of surface observations. Specific measurements for this purpose will also be discussed below.

2. Land Surface Measurements

a. Fallout model evaluation

Appropriate models are required for both prediction and assessment purposes; and since, the time of arrival, rate of arrival and cessation of fallout, as well as the distribution of particle sizes with time, at any specific location in the affected area constitutes the basic information which may be derived from the application of a model, it is necessary to make careful measurements of these quantities in order that proposed models may be evaluated.

(1) Time of arrival

Time of fallout arrival at a given location, like time of cessation, requires definition. Ordinarily it is defined as that time at which the measured activity level of deposited material or the observed ionization rate reaches some predetermined value above normal background. It is most effectively measured by an incremental collector, that is, by a sampling instrument which

collects deposited material over known time intervals for subsequent activity measurements; but it may also be determined from the record of any instrument which continuously measures ionization rate, such as the gamma time-intensity recorder. It is also possible to devise various combinations of radiation-sensitive triggering units and time-measuring devices for this purpose. Time of arrival is capable of being measured with more precision than most of the other required quantities, the principal sources of error being only improper definition and instrument malfunction.

(2) Rate of arrival

Rate of fallout arrival may also be measured by means of an incremental collector or with an instrument which records ionization rate as a function of time. The former is preferable, however, since the collected samples may be weighted and the rate of mass deposition determined, while the latter gives only the overall buildup of the radiation field. The activity of each incremental collector sample must be measured; and although there are many ways that this can be accomplished, one convenient method is to monitor the entire tray in a constant geometry arrangement. Either an instrument which measured ionization rate directly or a scintillant-photomultiplier system which yields a count rate may be used, provided they have been quantitatively related in advance; both kinds of information - roentgens per hour and disintegrations per minute - will ultimately be needed. The principal sources of error for this measurement, if made by an

instrument such as a gamma-time-intensity recorder, are its possible contamination and non-uniform response with respect to energy and direction. Collection bias, that is, the failure of the tray to collect a representative sample, may on the other hand introduce serious error in the incremental sampling method – as may faulty counter calibration. In either case, since it is primarily absolute values which are affected, rate measurements are reasonably reliable.

(3) Time of cessation

Time of fallout cessation must also be defined to be meaningful. Theoretically, when ionization rate is being observed, cessation occurs at the point on the curve where pure decay begins and, when the activity of deposited material is being measured, with the tray on which no activity above background is observed. Actually, however, both of these criteria are complicated by the fact that light secondary fallout often continues to arrive for some time after primary fallout has ceased. As before, although an incremental sample collector may be used to determine cessation, it is necessary to specify some cut-off activity level. If a gamma-time-intensity record is used, the exact location of the point of cessation will nearly always remain uncertain.

Typical plots of gamma-time-intensity recorder and incremental collector data are presented in Figures 1 and 2.*

*The figures referenced in this paper were not available at the time of publication. They may be obtained by contacting the author directly.

Examination of these figures will illustrate the preceding points and show how time of arrival, rate of arrival and time of cessation values may be obtained.

(4) Particle size distribution as a function of time

The time rate of arrival of fallout particles of different sizes may also be determined from samples collected incrementally. To do so, however, requires that the number of particles in each size group in each sample be counted. No instrument capable of doing this adequately exists at the present time, and even though several current developments show promise, it is still necessary to use time-consuming manual methods. One such method which was developed recently features the counting of particles on a photographic print of each tray enlarged ten times; past methods have utilized microscopic examination of small areas of the trays. One central question which must be decided before any counting procedure can be applied is what physical parameter to use as a measure of size. If the particle is being observed essentially in two dimensions and diameter is selected instead of projected area, the question of how the diameter of an irregular particle should be measured still remains. The diameter of the largest inscribed circle, the diameter of the smallest circumscribed circle, and the average diameter of the particle all lead to different terminal velocities; it has even been suggested, for this reason, that terminal velocity might itself be the best measure of size. Accordingly, the principal sources of error in determining particle size distributions, apart from possible

bias introduced into the sample by non-uniform collection efficiency, are observational in nature. Both of these tend to discriminate against the small sizes and it is likely, therefore, that most reported distributions are seriously in error in this range.

Figure 3 illustrates one way in which particle counting results may be presented.

b. Construction of mass and fraction of device per unit area contours

One of the ultimate goals of fallout research is to predict the atmospheric partition of nuclear debris and inert materials in order that material balances may be computed. Since it is very difficult to measure the fraction of material which remains suspended beyond the primary fallout period, it is of particular importance to make measurements of the local fallout which will permit contours of the mass of material and fraction of device deposited per unit area to be constructed. In addition to this, such information is of fundamental importance for the application of countermeasures and decontamination procedures.

Accurate total collections of the material deposited at a number of known points during the primary fallout period, which may subsequently be weighed and analyzed radiochemically or chemically for the fraction of the device they contain, will suffice for this purpose. It is important, however, that the sampling area of each collector be large enough to obtain a representative sample and that enough collectors be used to enable local variability to be estimated and contours to be constructed in some detail. Every effort must be made to avoid sample bias resulting from the collection of extraneous material or the loss of collected fallout

material. One instrument which has been used to make collections of this kind utilizes a collecting tray about 2 ft square with a polyethylene liner to facilitate sample removal and a hexcel insert to prevent material from blowing out. The tray is housed in a separate unit whose top cover may be opened just before the arrival of fallout and closed shortly after it ceases.

Collected samples are removed in the laboratory; their mass is determined gravimetrically and they are usually analyzed for some specific radionuclide such as Molybdenum-99 to determine the total number of fissions or fraction of the device present. The principal sources of error, with regard to mass, are sample bias and failure to recover part of the sample from the collecting tray; these also introduce error into fraction of device determinations but, in addition, radionuclide fractionation may seriously affect results. Significant errors probably exist in such measurements due both to collection bias and fractionation effects, and efforts are currently being made to arrive at quantitative assessments of these errors.

It is also to be noted that the total number of points from which data of this kind are obtained is nearly always small compared with the extent of the contaminated region. This means that contours must be grossly simplified, and it is likely that much significant detail is omitted in the process. Localized hot spots containing a significant fraction of the device may, for example, remain undetected.

Typical mass per unit area contours constructed from such information are shown in Figure 4.

c. Construction of ionization rate contours

Ionization rate measured a short distance above the surface in a

fallout area provides a direct measure of the gamma radiation which produces biological damage; it is essential, therefore, that ionization rate contours be constructed for the analysis of fallout events. Providing the decay rate is known, it is only necessary to measure the ionization rate accurately once at a given location on a land surface; any past ionization rate up to the time of fallout cessation, or any future ionization rate if the fallout material remains undisturbed, may then be computed. Accordingly, from ionization rate readings made under similar geometry at a number of different times and locations in the fallout area, and a series of geometrically identical readings made over a long enough interval at the same location to permit a decay curve to be plotted, ionization rate contours at any desired time, such as one or twelve hours after detonation, may be constructed for the area.

In practice, readings are made not only with instruments which measure ionization, such as certain survey meters, but also with instruments which count gamma-ray interactions, such as G-M tube and crystal counters. Such instruments are used, for example, in aerial surveys and for measuring the activities of total fallout samples. In each case, however, the instrument must be calibrated in terms of ionization rate; that is, the way in which its counting rate varies in radiation fields of known ionization rate must be determined; and unless caution is exercised, considerable error may be introduced during the calibration procedure. Care must also be taken to determine the energy and directional response of any instrument which is used, and both the energy spectrum of the radiation and the geometry of the measurement must be known before final ionization rate values may be derived.

It is evident that appreciable error may also be introduced into the construction of contours by the application of an erroneous decay rate, or by the application of a uniform decay rate if, as a result of radionuclide fractionation, the actual decay rate varies over the fallout area. For this reason not one but many decay measurements are ordinarily made, both at different locations in the field and on samples collected at different locations. If, as current studies indicate, the decay rate actually does vary with location for certain types of events, it will ultimately be necessary to express this variation quantitatively before accurate contours can be constructed.

It should also be noted that it is useful to record the total dose at a point where an ionization rate measurement is to be made by means of an appropriate dosimeter, for the difference between this value and the integral of the area under the decay curve will give the dose accumulated prior to the cessation of fallout. Such information is essential if contours of total dose to a given time are to be constructed. Complete ionization rate records, such as those provided by a gamma-time-intensity recorder, are preferable, of course; but it is usually not practical to install instrumentation of this kind on a large scale.

A set of ionization rate contours for a particular event and a time of one hour after detonation are given in Figure 5. It will be observed that in this case, too, the limited number of observation points has necessitated gross simplifications with a consequent loss of detail. Figure 6 shows a typical decay curve.

d. Characterization of fallout material

Knowledge of certain physical, chemical and radiochemical characteristics

of the material which is deposited as fallout is essential to the application of countermeasures and decontamination procedures, as well as for evaluation of the ingestion hazard. In addition, for the reasons given above, it is important to determine the energy spectrum of the gamma radiation associated with the material. Actual samples are required for each of these purposes, and it is customary to use some of those obtained from the incremental and total collectors described earlier.

Conventional chemical analyses are performed to determine the gross quantities of such elements as iron, aluminum, calcium and magnesium which are present in the sample, and microchemical techniques are often utilized to determine the composition of single particles and droplets. Physical studies, including density determinations, size measurements and observations of structure, are also performed on individual particles using a variety of laboratory methods.

The gamma spectrum of a fallout sample is usually measured on an instrument utilizing a crystal detector and containing a pulse-height analyzer. In the single-channel type of gamma spectrometer the pulses from the scintillation crystal-photomultiplier system are fed into the pulse-height analyzer after suitable amplification. The base line is swept slowly across the pulse spectrum and the output fed simultaneously into a count-rate meter. The result is a record of count rate, or gamma intensity, versus analyzer base line position, or gamma energy. The geometry of the detection system is of critical importance; unless a crystal of adequate size is used, much gamma photon energy will be lost by Compton scattering out of the crystal, and photon backscattering from shielding elements may produce additional error. Back-scattering must be minimized, therefore, and gross spectra corrected for Compton scattering before radionuclide identification

or the calculation of mean gamma energy is attempted. It is also necessary that a number of successive spectra taken on the same sample be examined before final conclusions are drawn, since the energy spectrum changes with time.

A gross gamma spectrum measured on a multi-channel spectrometer is presented, together with its calibration curve, in Figure 7.

3. Water Surface Measurements

Although the same information is required for model evaluation, contour construction, and material characterization regardless of whether fallout is deposited on a land or water surface, the measurement situation is complicated in the latter case by the settling and dissolving of the material. On a pre-positioned simulated infinite plane, such as a ship, essentially the same measurements may be made as on a land mass; except for an additional deposition bias due to the distortion of airflow around the ship itself, the two conditions are comparable. Indeed, some sort of fixed platform must be used to collect total mass and fraction of device samples, as well as to measure the rate of arrival and obtain samples for characterization studies. If, however, an isolated ionization rate measurement is made a short distance above the surface at some time after the cessation of fallout, this cannot in itself be used in the construction of ionization rate contours. It is necessary first to determine what this reading would have been had a solid surface existed at the point.

This requires both that the total fallout which was deposited at the point be computed, and that the response of the instrument to the radiation from the fallout remaining suspended in a thin surface layer be calibrated. To accomplish the former it is necessary to know the distribution of the

fallout activity over its total depth of penetration. This activity profile may be integrated to yield the total activity deposited; or, if it can be established that the activity is uniformly distributed, then it is only necessary to know the depth of penetration at the point and the activity at a single depth. If the time of fallout arrival is known, and it can be established that the rate of penetration is constant, the depth of penetration can be computed; and with a calibrated instrument the required activity reading can be derived from a reading taken above the surface, perhaps by aerial survey.

In practice activity profiles are usually measured with probes containing G-M tube, scintillant or ionization detection units which are lowered into the water to the total depth of penetration. It is evident that if, as is probably the case for solid particulate, a portion of the fallout has penetrated below the maximum depth of observation at the time the profile is taken, the integrated activity will be in error. Such probes must also be calibrated for the four-pi water condition and additional error is often introduced in this way. Instrument contamination is another effect to be reckoned with, as is the marked irregularity of the measured profiles; because of these factors it is even difficult at times to determine the depth of penetration with any degree of accuracy.

The errors inherent in this procedure are probably small compared with those which enter into the aerial survey method, however. Material lost to greater depths, non-uniform penetration and erroneous arrival times all may lead to serious error in computing the total fallout. Additionally, certain radionuclides appear to go into solution much more rapidly than others, meaning that the energy spectrum of the radiation may be quite

unrepresentative in and above a thin surface layer. Thus, apart from possible fractionation with position due to the changing distribution of particle sizes, radionuclide fractionation with depth may also have to be considered. Under such conditions accurate instrument calibration becomes extremely difficult, with the result that significant errors from this source may also be introduced into final activity values.

4. Summary

The attempt has been made in the preceding sections to indicate the principal sources of error in experimental fallout measurements. Unfortunately the magnitude of most of these errors cannot be estimated at the present time. As a result of the data accumulated at Operation REDWING, however, it appears that it may be possible to do so in the near future. Once this has been accomplished we will be in a position to estimate the reliability of measurements which have been made in the past and, consequently, to predict or assess the nature of any future radiological event with greater accuracy. In the meantime, the importance of inquiring into any given set of experimental data for the inherent measurement errors it may contain cannot be over-estimated.

APPENDIX J

THE RELATIONSHIP OF TIME OF PEAK ACTIVITY FROM FALLOUT TO TIME OF ARRIVAL

P. D. La Riviere

USNRDL-TR-? (in publication)

Data was presented indicating that time of peak intensity due to fallout was related to time of arrival by the simple equation $t_p \simeq 2t_a$. for the ranges t_a 0.013 – 12.4 hr

$$\text{yield range} \left(\frac{\text{max}}{\text{min}}\right) = 15{,}000$$

scaled depth (–)2.2 to 5.1

Preliminary time of cessation (t_c) data indicate the empirical equation $t_c \simeq 5t_a^{0.7}$ ($t_a \leq 12$ has times in hours after shot) holds for Redwing shots.

APPENDIX K

Fraction of Weapon Debris in Local Fallout

L. Werner

The prepared paper covering fraction of weapon debris in local fallout presented the following:

It was first pointed out that at least three applications of fraction-of-device values suggest themselves: (1) As a check on gamma dose contours, (2) As a fallout theory parameter, and (3) As a means of estimating the contribution to long-range fallout. In no case have fraction-of-device measurements been designated as primary objectives of field test programs; they have been performed as an incidental aspect of field data analysis.

Fraction of device may be defined on the basis of total material, both beta activity, total gamma activity, selected indicator elements, etc. These definitions become identical only if no fractionation among elements occurs. Such fractionation does occur, but insufficient data has existed to date for any assumption but one of no fractionation to be made.

Three approaches have been utilized for measurement and computation:

(1) Sampling of the fallout field and analysis of weapon debris.

(2) Measurement of gamma dose rates in the fallout field.

(3) A combination of (1) and (2).

Each method was discussed in terms of data needed and sources of possible error. In connection with the dose rate method, the relationships between roentgens per hour and radioactivity per unit area of the source was discussed. It was emphsized that no single constant exists expressing this relationships, but that one must be computed for the specific conditions of each shot considered. Thus the value in Effects of Atomic Weapons is an approximation only to one set of conditions of source energy

and surface density.

The exact method of computation was presented, and the results of a number of computation for various shots were shown. For shots of various types the fractions generally lay in the range 0.16 to 1.

It was emphasized that no basis for estimating accuracy exists, although precision may be calculated.

If such measurements are to be made in the future the following three-point approach was recommended:

1. Refinement and development of fallout models and measurement of atomic cloud characteristics and properties.
2. Extensive direct sampling or collections of fallout at a sufficient number of locations to provide statistical sampling of the fallout field.
3. Comprehensive surveys of fallout fields to an extent sufficient to characterize the fallout field within pre-selected confidence limits.

APPENDIX L

Analysis of Jangle and Castle Data

C. F. Miller

Some results of an analysis of fallout data from Operations Jangle and Castle were discussed. The intent of the paper was to show correlations between particle trajectory analyses and certain aspects of the fallout patterns such as the "hot line," outer peak activity, and general direction of the contour lines. A graphical method for determining location and direction of the contours was required before such correlations and correlations to mass and fraction of device could be made. Parameters pertinent to radiological countermeasure systems were enumerated.

APPENDIX M

Project 2.63 Water Survey

Sanford Baum, USNRDL

Certain studies of project 2.63, Redwing, indicate that the penetration behavior of some portion of the fallout material may be predicted with the aid of some simple parameters. For water shots, the tentative conclusion is that the parameters describe the penetration of all the fallout material. For land shots, the tentative conclusion is that the parameters describe the behavior of an amount which is significantly less than the total; furthermore, this deficit can be expected to vary from point to point. It is therefore concluded that the estimation of land-equivalent fallout from oceanic measurements is more feasible for water shots than it is for land shots. This conclusion is based on the additional, and unproven, assumption that the penetration parameters do not vary from point to point, or that if they do, they can be successfully estimated.

APPENDIX N

Gas Analysis Data from Redwing and Its Interpretation with Reference to the Fallout Problem

K. Street

As you recall, samples of gaseous debris as well as particulates were collected on a number of the Redwing events. The experimental arrangement consisted of a probe designed to sample isokinetically extending from the front of the sampling aircraft. This stream was filtered through IPC filter paper to remove the particulates, then went through a compressor and the gaseous fraction was stored in a pressure vessel. The filter paper was dissolved and analyzed for Mo^{99}. The gaseous fraction was separated and among other things the Kr^{88} was determined. Kr^{88} (2.7 hour) having only short-lived precursors should represent pretty well the behavior of gases in the cloud. Mo^{99} on the other hand probably represents fairly well the "gross activity" of the particulate debris (i.e., some things fall out to a greater extent and some to a lesser extent). At any rate, it is a useful reference isotope with which the fractionation of other species can be compared.

The data of Momyer, Goishi, and da Roza are shown in Figs. 1-3. The ordinate is the ratio of fissions in the sample as determined by Kr^{88} to fissions as determined by Mo^{99}. Thus in a cloud in which there has been no separation of gases and particulates, this ratio would be one. The abscissa is the sampling altitude in thousands of feet. Samples belonging to the same event are connected by lines and named by an abbreviation -- Ap for Apache, Mo for Mohawk, etc. Numbers beside a point and not enclosed in parenthesis are the Sr^{90} R-factors as measured on the large radiochemistry

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filter papers from the same aircraft. The R-factors for the LASL shots were supplied by George Cowan. Numbers in parenthesis are sampling times in minutes after shot time. The fission ratios are probably accurate to $\pm$ 50 per cent.

If one assumes, as is likely, that the action of gravity is the main mechanism for the separation of particulate fission products from gaseous fission products, then these data can be interpreted to give some indication of the "amount of fallout" for some of the Redwing events. In this interpretation, the gas (Kr^{88}) is assumed to represent the starting position of the fission products. If there were no action of gravity (all very fine particles), the ratio f_{Kr}/f_{Mo} should be one at all points. If there is any fallout (some, though possibly a small percent of larger particles), then one could find low (even zero) values of the ratio f_{Kr}/f_{Mo} in low parts of the cloud or under shear layers. This indicates that there has been some fall of particulates but it is not quantitative. This if the percent of material falling out is small, the bulk of the cloud could still give ratios near one. On the other hand, if one finds a very high value for f_{Kr}/f_{Mo}, it indicates that this region of space is very depleted in particulates and that a large fraction of them must have "fallen out." By "fallen out" here I think we mean that they have fallen a few thousand feet (one or two) at least in a few hours (sampling times are typically 1 to 4 hours after shot time), and therefore would reach the ground in a day or two. Thus at PPG, this material would end up in the Pacific Ocean, but a fair fraction ($\sim$ 1/3) might not be included in a "local few-hundred-mile type ground survey."

The ground shots, Lacrosse, Mohawk, and Zuni, show regions highly

depleted in Mo^{99} $\left(\frac{f_{Kr}}{f_{Mo}} = 10 \text{ to } 25\right)$, which would indicate "fallout" to the extent of 90 to 95 per cent. Barge shots show no highly depleted regions $\left(\frac{f_{Kr}}{f_{Mo}} < 1.7\right.$ in all cases). Of these, Huron is probably the most significant since it was small enough to sample fairly adequately. It should be quite comparable to Mohawk. For the larger yield shots, the sampling altitudes are all quite low in the cloud. The only high altitude sample on Cherokee gave a ratio of one as would be expected for very little fallout.

The Sr^{90} is high relative to Mo^{99} (R-factors are high - - 1.5 to 2.0 where they should be 0.6 to 0.7 for the bomb) by factors of 2 or 3 in the material "remaining up" after extensive fallout (see Mo and Zu). Thus, while 90 to 95 per cent of the Mo^{99} (and gross activity) may fall out on a ground surface shot, 10 to 30 per cent of the Sr^{90} may "remain up" and become part of the world-wide circulation. Though Sr^{90} is not brought down as effectively as Mo^{99}, this is not an insignificant scavenging action in itself.

Fallout gamma surveys indicate that about 20 to 30 per cent of a typical barge shot falls out within a few hundred miles. Only particles larger than 75μ can fall within this distance, and there may be another 50 per cent as much activity on 25 to 75μ particles that would fall out within a few thousand miles. Thus 30 to 40 per cent of the activity from a typical barge shot may "fall out" in the Pacific. This is consistent with the "depletion of particulates" we find in probe samples on barge shots. Sr^{90} does not appear to fractionate as severely on a barge shot as on ground surface shots, but if anything it is also "richer" in the material that stays up. Thus a large barge shot may put 60 to 80 per cent of its Sr^{90} into the world-wide circulation. The aerial gamma surveys should be considerably better for barge shots than for ground shots, since the

radioactive particles from barge shots are very small and are brought down by being incorporated in large salt water slurries. These will dissolve in the ocean and will leave the activity above the thermocline. On the other hand, some coral particles from a ground shot will sink before a survey can be made, leading to low estimates of the fraction "fallen out" if this effect is not corrected for.

Tewa was part water, part ground shot. It fractionated like a land shot, but we found no "particle-depleted" regions in the probe sampling. I think this is most likely due to the low sampling altitudes relative to the cloud size.

To summarize, I think there is an indication that the land shots are considerably more effective in scavenging Sr^{90} (by a factor of from 2 to 8) than barge shots, and that most of the world-wide Sr^{90} should therefore have come from the large yield airdrops and barge shots. It should be emphasized that this is a lot of interpretation on very little data, and that there are a lot of loop holes in both the data and the interpretation.

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APPENDIX P

Accuracy of Fallout Predictions

V. Shelton

This discussion will concern the validity of fallout predictions as they have been made for test Operations TEAPOT and REDWING and are proposed for PLUMB BOB, together with an estimate of the quality of the model and the scaling ideas incorporated into predictions.

Fallout Fraction

The fraction of the fission activity which is expected to fall out within the first 24 hours after detonation is currently predicted according to the method of UCRL 4660, which related fallout quantity to yield, surface conditions, surface overpressures, and tower and device masses. This method predicts the amounts of fallout to be expected from detonations at various burst heights, with and without towers. The fallout fractions as calculated are usually within 20 percent of the measured values, for the 20 or 25 Nevada shots for which reasonably good data are available. It predicts fallout of about 75 percent of the bomb for surface bursts on land or water of any yield. Whether or not this number is correct for megaton weapons on barges or on land cannot be readily determined at this time because of the nebulous character of fallout measurements over ocean area, but 75 percent is felt to be a safe estimate for most shots, in the sense that the measured values usually indicate the correct value to be less than 75 percent, at least for barge shots.

Activity Distribution, Cloud

All of the fallout-pattern data from Operations TUMBLER-SNAPPER, BUSTER-JANGLE, UPSHOT-KNOTHOLE, TEAPOT, and CASTLE have been used to

develop a model of fallout quantity versus fall rate to the ground as a function of position in the cloud at 5-10 minutes after zero time--the so-called stabilized cloud status. The fall rates are assigned particle sizes, according to aerodynamic theory, for convenience, but it is fall time which is important to prediction; one does not know how to calculate fall rate, given particle size, for the particles of peculiar shape and variable densities which really exist in the cloud.

The same model is used for shots of all yields, detonated aloft or on the surface on land or water. It must not be true that particle sizes and distributions are the same for land and water shots, but existing data is not good enough to indicate the magnitude or character of the difference between land and barge shot fallout patterns. One would expect air bursts and water shots to produce smaller particles and more elongated fallout patterns than land shots. Air bursts in Nevada do create a fallout pattern whose shape and intensity distribution differ markedly from that for tower or land shots, and an effort will be made before and during PLUMB BOB to develop and use a cloud model for this class of detonation.

Prediction Accuracy

Predictions of fallout for the tests have dealt with the gamma intensity at three feet above the surface at the time of fall, the time of arrival, and the decay of this gamma intensity during the period of significant radiation intensities. No attempt has been made to predict the beta or alpha intensities or to estimate the density on the ground of any particular isotope, such as Sr^{90}. The extent to which accuracies are known is dependent upon the extent and quality of the measured data, and will be discussed relative to various burst conditions.

1. Tower Bursts, Nevada

When meteorology and yield are both known as precisely as possible, that is, after the event, gamma intensities as calculated agree with the best measured values within a factor of two or better for most shots. Predictions seem to be most accurate in the region from about 20 miles to 150 miles from ground zero. Close-in intensities do not compare quite as well, and measurements beyond 150 miles are too skimpy to provide a meaningful comparison.

Normal variations in yield from the expected value can impose an error of up to another factor of two, which adds to the before-detonation uncertainties.

Variations of winds from the predicted values usually shift the main axis of the fallout pattern without much distortion of the shape of the isodose contours, so that one expects the extent of a given radiation contour to be fairly independent of usual 6-hour wind shifts, even though the bearing of the axis of the contour may rotate 20° from the predicted direction. If yield is as expected, then we usually predict the intensity at any point in the pattern to better than a factor of two, and the bearing of the hot line to within 20° or less. This means, with the narrow patterns usually found in Nevada, that a prediction of dose at any particular point on the ground can be off by a factor of 10 or more.

2. Surface Bursts, Nevada

Forecasting for low-yield surface bursts in Nevada has been done by simple wind scaling from JANGLE Surface Shot. Full scale calculations with the complete model yield about the same results, and agree with [redacted]

the well-measured portion of the pattern by a factor of two or better on dose.

3. Air Bursts, Nevada

Particle size distributions and pattern shapes are considerably different for air-bursts. Predictions for air bursts have not been made in the past because such shots do not seem to put down significant quantities of activity, but an effort will be made in PLUMB BOB to make quantitative calculations for fallout from the balloon shots, with a new cloud model based on past continental air bursts.

4. Surface Bursts, Pacific

Fallout intensity predictions for large-yield detonations in the Pacific are based on precisely the same model which is used in Nevada, simply because the experimental data are not extensive enough to provide a real basis for changing this model. All that can be said about accuracies is that the model predicts CASTLE Bravo intensities at Rongelap and Bikar which are of the correct magnitude when time-space adjusted winds are used, and does as well for REDWING Tewa and Flathead. REDWING measurements have not been thoroughly compared with calculations at this time.

Model Accuracy

The correctness of a model can be estimated only by comparison of calculated with observed fallout patterns after weather, cloud height, and yield uncertainties have been removed as far as is possible. The model should be based upon all shots for which data is available, rather than on a single event such as CASTLE Bravo, for which dozens of quite different models can be used which will match the observed data.

APPENDIX Q

The Close-in Fallout Fraction for Nevada Bursts

K. Nagler

Of interest in model construction and scaling is the fraction of the total gamma activity of fission products which falls in the important fallout region and some idea of the uncertainties in computing this fraction. The accompanying table gives an idea of the uncertainty in estimates of the fraction of the total activity which comes down as close-in fallout for a selection of Nevada bursts. The percentages were all estimated using the relationship from the Effects of Atomic Weapons that a dose rate at monitoring level of 1200 R/hr would result at H + 1 if the fission products from 1 kiloton of fission yield were distributed over 1 square mile.

The Weather Bureau estimates of the probable percent of the total activity which fell in the first 200 miles are given in column 3. Since, however, the amount falling within a specific distance from the burst site is dependent on the wind speed, the probable percentages have also been estimated out to the farthest distance that debris of a particular fall rate ("F", in Weather Bureau nomenclature) landed, as estimated from fallout plots. The "F" fall rate is 30,000 feet (i.e., from 35,000 feet MSL to 5,000 feet MSL) in 6 hours. This distance for each of the bursts for which this integration was made is given in column 9.

In order to estimate the variability in making the estimate for columns 3 and 7, Mr. Telegadas estimated in each case the lowest and highest amounts which could reasonably be assumed from the monitoring data. For example, along arcs near which several monitoring runs were made, it is possible to estimate the integrated activity at that distance on the

basis of the higher readings, the lower readings, or what one considered the most probable selection of readings. Also, there is subjectivity in interpolation and extrapolation in regions of no measurements. Columns 2 and 4, and columns 6 and 8 show the possible extremes that might arise from such uncertainties.

In column 5, the data are from RAND Report R-265 and were calculated from Col. N. M. Lulejian's analyses of fallout patterns—based, in part, on aircraft measurements not given much weight in the Weather Bureau analyses. In column 10, the estimates of the fraction down are those prepared by Dr. A. V. Shelton of U.C.R.L.; using a different method of integration may lead to an even greater uncertainty in the estimation of the fraction of the total activity which falls close to the burst site.

Of the most probable amount of activity occurring within 200 miles of the burst site, an attempt was made to determine what fraction came from the altitudes of the stem of the nuclear cloud. Estimates were made for five bursts in which the wind was such as to spread out the fallout plot so that stem and mushroom head material could be separated. The resulting percentages are given in column 13; the assumed cloud and stem heights are given in columns 11 and 12. It should be pointed out that there are large errors in estimating the stem fraction, so that the numbers in column 13 might well be subject to a large error. Another fact to be noted is that most of the stem fraction settles rather close to the burst site, apparently from very large particles.

It is, of course, possible that some other mechanism than the settling of individual particles accounts in part for the appearance of that radio-

activity in stem areas of the fallout plot. Nevertheless, unless fallout computations are to be made in some radical manner, it seems necessary to attribute some activity to the stem altitudes of the nuclear cloud. The 3 per cent estimate mentioned as possible for large weapons does not seem reasonable for Nevada type bursts. It might be noted, however, that from the 3rd CASTLE shot - a ground burst several times the yield of the Nevada detonations - there appeared to be a considerably smaller fraction of stem debris than in Nevada tower bursts. Thus, there may be an indication that clouds from large-yield weapons have smaller fractions of stem activity and/or that the environment of the Pacific Proving Ground in somehow less conducive to stem debris.

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Burst		Percent of total activity falling within 200 miles				Percent of total activity within distance to farthest extent of "F" particles				Percent falling in first day (Shelton)	Assumed heights (feet MSL)		Apparent per cent of close-in fall-out from stem altitudes
		Min.	Probable	Max.	RAND	Min.	Probable	Max.	Distance (miles)		Top of cloud	Top of stem	
1		2	3	4	5	6	7	8	9	10	11	12	13
Tumbler-Snapper	5	13.8	15.6	17.4	24	15.2	17.8	20.3	272	–	–	–	–
	6	10.6	12.9	15.2	17	10.1	12.3	14.4	150	–	40,000	25,000	25
	7	6.4	8.7	11.0	13.5	6.5	8.9	11.2	208	12	–	–	–
	8	11.2	13.1	15.0	7.6	7.0	7.8	8.6	184	–	–	–	–
Upshot-Knothole	1	5.2	6.6	8.0	24.6	5.6	7.0	8.3	310	10	–	–	–
	2	7.1	8.0	8.8	13.1	7.0	7.8	8.6	192	12	41.000	26,000	23
	3	4.9	5.8	6.7	1	–	–	–	–	–	–	–	–
	5	12.9	13.5	14.1	15	–	–	–	–	11	–	–	–
	6	–	14	–	20	–	–	–	–	12	–	–	–
	7	–	16	–	20.4	–	–	–	–	12	–	–	–
	9	–	19	–	17.9	–	–	–	–	33	–	–	–
	10	–	1	–	1	–	–	–	–	2	–	–	–
Teapot	2	–	–	–	–	–	10	–	175	9	–	–	–
	3	–	–	–	–	–	12	–	100	9	–	–	–
	5	–	–	–	–	–	9	–	150	10	–	–	–
	6	–	–	–	–	–	1	–	215	5	–	–	–
	8	3.0	5.6	8.2	–	2.9	5.4	7.9	170	3	32,000	21,500	19
	11	4	7	10	–	–	–	–	–	4	–	–	–
	12	–	–	–	–	–	10	–	350	13	–	–	–
	13	5.0	8.0	12.5	–	4.0	7.0	11.0	145	10	43,000	29,000	35
	14	1.8	3.0	4.4	–	1.9	3.1	4.6	240	4	36,000	25,500	48

Probably the best parameter to use as a standard agreement is a specific contour extent and width as a function of radial extent. Dose rates at any one spot on the ground are sometimes very sensitive to minor wind variations and, therefore, are not always a reliable indicator of model accuracy.

Whether or not any particular model is good enough depends entirely upon the use to which it is to be put. As far as test operations are concerned, if one can be sure of predicting the real dose at a given radial distance from ground zero within a factor of two and the width of any particular contour within a factor of two, at distances up to 200 miles, the operational problems can be handled reasonably well. Meteorological uncertainties will normally create larger pre-shot errors than the above, even in test operations, and will almost certainly be one of the major unknowns in any tactical situation, along with yield and height of burst.